The Effects of

Nuclear Weapons

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Editor

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Reprinted February 1964

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Foreword

This book is a revision of "The Effects of Nuclear Weapons" which was issued in 1957. It was prepared by the Defense Atomic Support Agency of the Department of Defense in coordination with other cognizant governmental agencies and was published by the U.S. Atomic Energy Commission. Although the complex nature of nuclear weapons effects does not always allow exact evaluation, the conclusions reached herein represent the combined judgment of a number of the most competent scientists working on the problem.

There is a need for widespread public understanding of the best information available on the effects of nuclear weapons. The purpose of this book is to present as accurately as possible, within the limits of national security, a comprehensive summary of this information.

Robert S. McNamara

Secretary of Defense

Glenn T. Seaborg

Chairman
Atomic Energy Commission

in tests, and would certainly be unpredictable in the event of an attack. Furthermore, two weapons of different design may have the same explosive energy yield yet differ markedly in their actual effects. Where such possibilities exist, the text calls attention to the limitations of the data presented and of the appropriate scaling laws.

The phenomena of air blast, ground and water shock, thermal (heat) radiation, and nuclear radiations associated with nuclear explosions are very complex. The descriptions of these phenomena and their related effects are thus somewhat technical in nature. However, this book has been organized in such a manner as to serve the widest possible range of readers. With this end in view, most of the chapters are presented in two parts. The first consists of a general treatment of a particular topic in a less technical manner, whereas the second discusses some of the more technical aspects. The material is so arranged that the reader will experience no loss of continuity by the omission of any or all of the more highly technical sections. It is hoped that this format, which was also used in the previous edition, will permit the general reader to obtain a good understanding of each subject without the necessity for coping with the technical aspects with which he may not be concerned. On the other hand, the technical material is available for the use of specialists, such as architects, engineers, medical practitioners, and others, who may have need of such information in their work connected with defense planning.

Many organizations and individuals assisted in one way or another in the production of this revision of "The Effects of Nuclear Weapons," and their cooperation is acknowledged with gratitude. In particular, sincere thanks are due to Colonel T. A. Irving and Lieutenant J. L. Wray, Defense Atomic Support Agency, Headquarters; to Captain R. K. Parsons, Defense Atomic Support Agency, Field Command; and to R. L. Corsbie and L. J. Deal, U.S. Atomic Energy Commission, Division of Biology and Medicine, for their help in solving the numerous administrative, technical, and other problems which arose during the preparation of this book.

Advantage has been taken of this new printing to make some changes and additions, as well as to correct a few typographical errors. New laboratory measurements on the ignition of various fabrics and household materials (Tables 7.40 and 7.66) indicated that the fire hazard from thermal radiation was significantly less than implied in the first (April 1962) printing. It was felt, therefore, that the corrections in Chapter VII should be made at the earliest opportunity. Other changes of a minor nature have been introduced in this chapter to clarify certain aspects of the development and spread of fires. In addition, the compilation of Announced Nuclear Detonations in Appendix B has been extended through 1963.

Los Alamos, N. Mex. SAMUEL GLASSTONE
February 1964

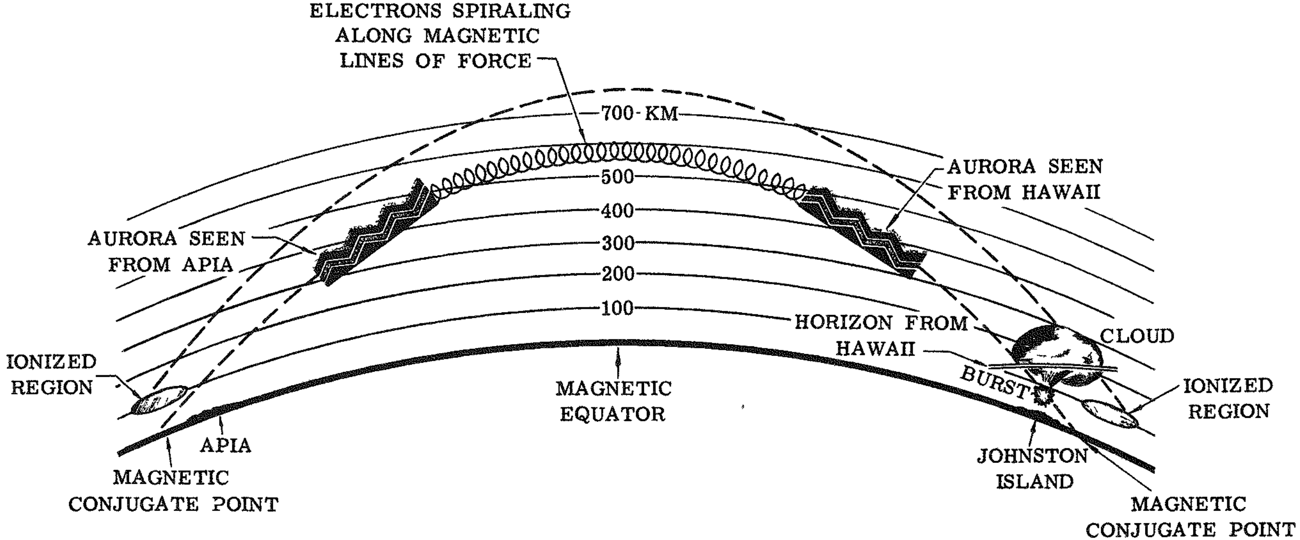


Figure 2.127. Phenomena associated with high-altitude explosions.

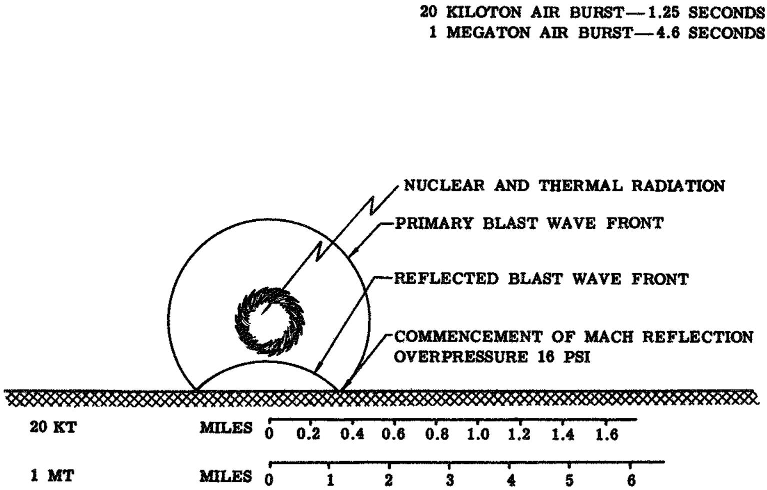


Figure 2.51b. Chronological development of an air burst; 1.25 seconds after 20-kiloton detonation; 4.6 seconds after 1-megaton detonation.

When the primary air blast wave from the explosion strikes the ground, another blast wave is produced by reflection. At a certain distance from ground zero, which depends upon the height of burst and the energy yield of the weapon, the primary and reflected wave fronts fuse near the ground to form a single, reinforced Mach front (or stem).

The time and distance at which the Mach effect commences for the air bursts at the given heights are as follows:

Explosion yield	*Height of burst (feet)*	*Time after detonation (seconds)*	*Distance from ground zero (miles)*
20 kilotons	1, 760	1. 25	0. 35
1 megaton	6, 500	4. 6	1. 3

The overpressure at the earth's surface is then 16 pounds per square inch.

Significant quantities of thermal and nuclear radiations continue to be emitted from the fireball.

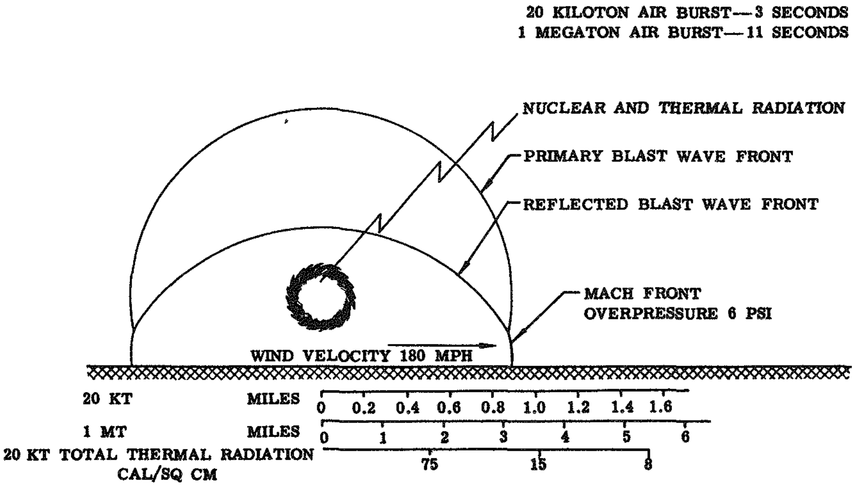


Figure 2.51c. Chronological development of an air burst; 3 seconds after 20-kiloton detonation; 11 seconds after 1-megaton detonation.

As time progresses, the Mach front (or stem) moves outward and increases in height. The distance from ground zero and the height of the stem at the times indicated are as follows:

Explosion yield	*Height of burst (feet)*	*Time after detonation (seconds)*	*Distance from ground zero (miles)*	*Height of stem (feet)*
20 kilotons	1, 760	3	0. 87	185
1 megaton	6, 500	11	3. 2	680

The overpressure at the Mach front is 6 pounds per square inch and the blast wind velocity immediately behind the front is about 180 miles per hour.

Nuclear radiations from the weapon residues in the rising fireball continue to reach the ground. But after 3 seconds from the detonation of a 20-kiloton weapon, the fireball, although still very hot, has cooled to such an extent that the thermal radiation is no longer important. The total accumulated amounts of thermal radiation, expressed in calories per square centimeter, received at various distances from ground zero after a 20-kiloton air burst, at 1,760 feet, are shown on the scale at the bottom of the figure (for further details, see Chapter VII). Appreciable amounts of thermal radiation are still received from the fireball at 11 seconds after a 1-megaton explosion; the thermal radiation emission is spread over a longer time interval than for an explosion of lower energy yield.

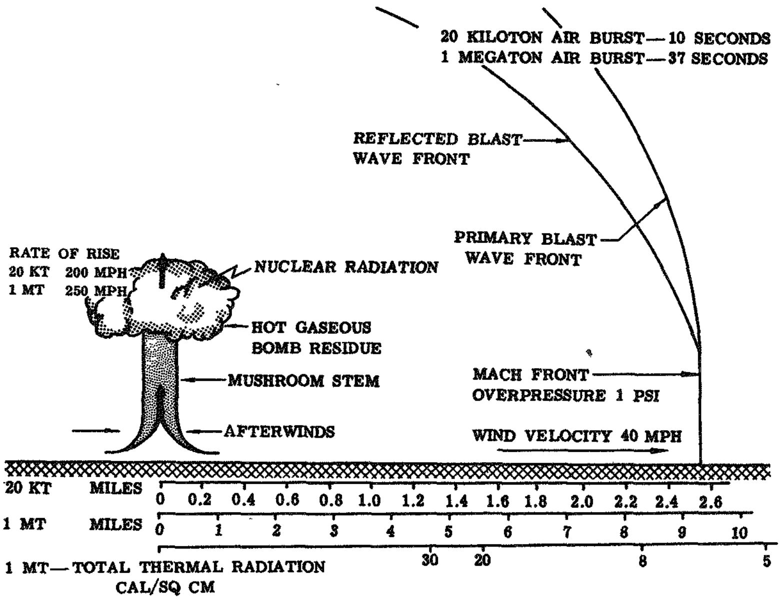


Figure 2.51d. Chronological development of an air burst; 10 seconds after 20-kiloton detonation; 37 seconds after 1-megaton detonation.

At 10 seconds after a 20-kiloton explosion at an altitude of 1,760 feet the Mach front is over 2½ miles from ground zero, and 37 seconds after a 1-megaton detonation at 6,500 feet, it is nearly 9½ miles from ground zero. The overpressure at the front is roughly 1 pound per square inch, in both cases, and the wind velocity behind the front is 40 miles per hour. There will be slight damage to many structures, including doors and window frames ripped off, roofs cracked, and plaster damaged. Glass will be broken at overpressures down to ½ pound per square inch. Thermal radiation is no longer important, even for the 1-megaton burst, the total accumulated amounts of this radiation, at various distances, being indicated on the scale at the bottom of the figure. Nuclear radiation, however, can still reach the ground to an appreciable extent; this consists mainly of gamma rays from the fission products.

The fireball is no longer luminous, but it is still very hot and it behaves like a hot-air balloon, rising at a rapid rate. As it ascends, it causes air to be drawn inward and upward, somewhat similar to the updraft of a chimney. This produces strong air currents, called afterwinds. For moderately low air bursts, these winds will raise dirt and debris from the earth's surface to form the stem of what will eventually be the characteristic mushroom cloud.

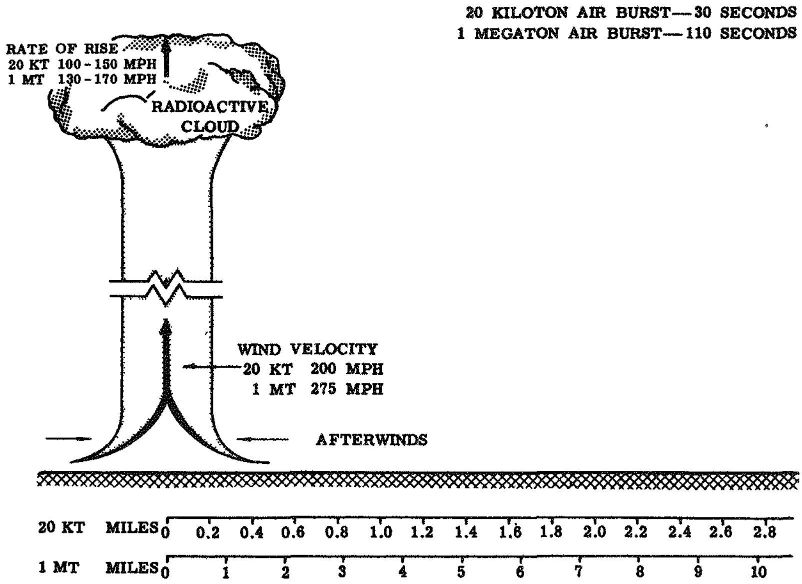


Figure 2.51e. Chronological development of an air burst; 30 seconds after 20-kiloton detonation; 110 seconds after 1-megaton detonation.

The hot residue of the weapon continues to rise and at the same time it expands and cools. As a result, the vaporized fission products and other weapon residues condense to form a cloud of highly radioactive particles. The afterwinds have velocities of 200 or more miles per hour, and for a sufficiently low burst they will continue to raise a column of dirt and debris which will later join with the radioactive cloud to form the characteristic mushroom shape. At the times indicated, the cloud from a 20-kiloton explosion will have risen about 1½ miles and that from a 1-megaton explosion about 7 miles. After about 10 minutes, the maximum heights attained by the clouds will be about 7 miles and 14 miles, respectively. Ultimately, the particles in the cloud will be dispersed by the wind and, unless there is precipitation, there will usually be no early (or local) fallout. Only if the height of burst is less than about 600 feet for a 20-kiloton and 3,000 feet for a 1-megaton explosion would appreciable early fallout be expected.

Although the cloud is still highly radioactive, very little of the nuclear radiation reaches the ground. This is the case because of the increased distance of the cloud above the earth's surface and the decrease in the activity of the fission products due to natural radioactive decay.

100 KILOTON SHALLOW UNDERWATER BURST—2 SECONDS

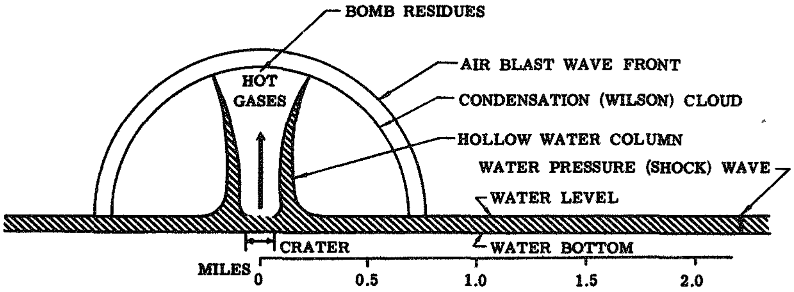


Figure 2.80a. Chronological development of a 100-kiloton shallow underwater burst: 2 seconds after detonation.

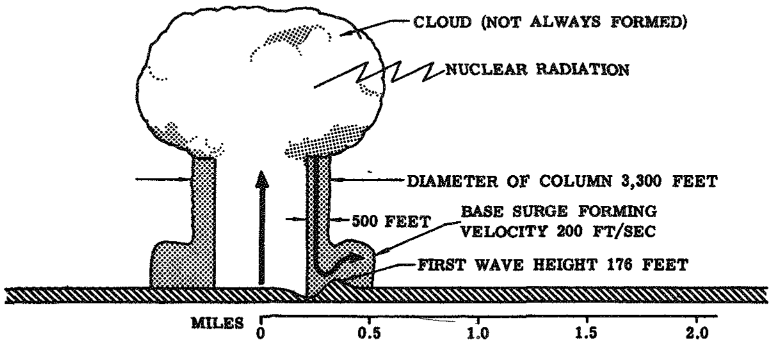
CHRONOLOGICAL DEVELOPMENT OF SHALLOW UNDERWATER BURST

When a nuclear weapon is exploded under the surface of water, a bubble of intensely hot gases and steam is formed which will burst through the surface if the detonation occurs at a shallow depth. As a result, a hollow column of water and spray is shot upward, reaching a height of over 5,000 feet in 2 seconds after a 100-kiloton explosion. The gaseous weapon residues are then vented through the hollow central portion of the water column.

The shock (or pressure) wave produced in the water by the explosion travels outward at high speed, so that at the end of 2 seconds it is more than 2 miles from surface zero. The expansion of the hot gas and steam bubble also results in the formation of a shock (or blast) wave in the air, but this moves less rapidly than the shock wave in water, so that the front is some 0.8 mile from surface zero.

Soon after the air blast wave has passed, a dome-shaped cloud of condensed water droplets, called the condensation cloud, may form for a second or two. Although this phenomenon is impressive, it has apparently no significance as far as nuclear attack or defense is concerned.

For an underwater burst at moderate (or great) depth, essentially all of the thermal radiation and much of the initial nuclear radiation is absorbed by the water.



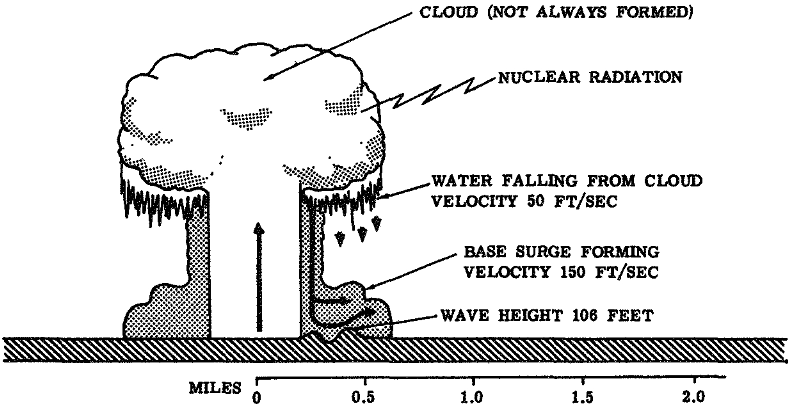
100 KILOTON SHALLOW UNDERWATER BURST—12 SECONDS

Figure 2.80b. Chronological development of a 100-kiloton shallow underwater burst: 12 seconds after detonation.

At 12 seconds after the 100-kiloton explosion, the diameter of the water column is about 3,300 feet, and its walls are some 500 feet thick. The weapon residues venting through the hollow central portion condense and spread out to form the cauliflower-shaped cloud, partly obscuring the top of the column. The cloud is highly radioactive, due to the presence of fission products, and hence it emits nuclear radiations. Because of the height of the cloud these radiations are a minor hazard to persons near the surface of the water.

At 10 to 12 seconds after a shallow underwater explosion, the water falling back from the column reaches the surface and produces around the base of the column a ring of highly radioactive mist, called the base surge. This ring-shaped cloud moves outward, parallel to the water surface, at high speed, initially 200 feet per second (135 miles per hour). For underwater bursts at certain depths, the radioactive cloud may not be formed, although there will generally be a base surge.

The disturbance due to the underwater explosion causes large water waves to form on the surface. At 12 seconds after a 100-kiloton explosion, the first of these is about 1,800 feet (0.34 mile) from surface zero, and its height, from crest to trough, is 176 feet.



100 KILOTON SHALLOW UNDERWATER BURST—20 SECONDS

Figure 2.80c. Chronological development of a 100-kiloton shallow underwater burst: 20 seconds after detonation.

As the water and spray forming the column continue to descend, the base surge cloud develops, billowing upward and moving outward across the surface of the water. At 20 seconds after the 100-kiloton explosion the height of the base surge is about 1,000 feet and its front is nearly ½ mile from surface zero. It is then progressing outward at a rate of approximately 150 feet per second (100 miles per hour).

At about this time, large quantities of water, sometimes referred to as the massive water fallout, begin to descend from the radioactive cloud, if it is formed. The initial rate of fall is about 50 feet per second. The diameter of the column has now decreased to 2,000 feet.

By the end of 20 seconds, the first water wave has reached about 2,000 feet (0.38 mile) from surface zero and its height is roughly 106 feet.

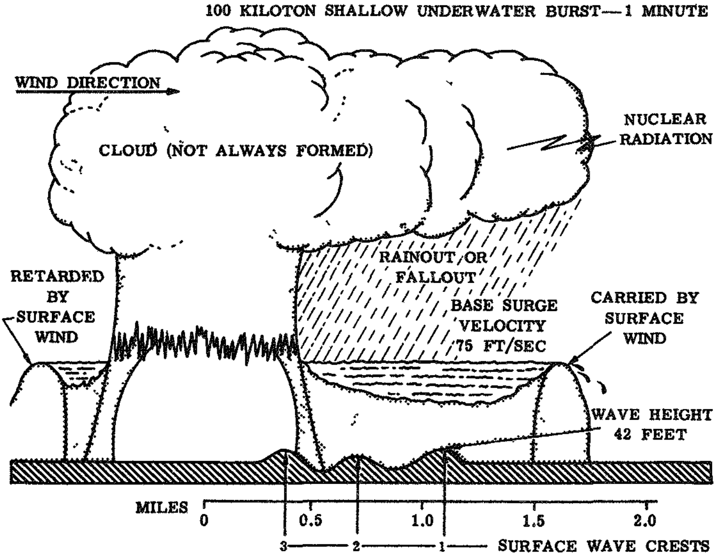


Figure 2.80d. Chronological development of a 100-kiloton shallow underwater burst: 1 minute after detonation.

At 1 minute after the underwater burst, the water falling from the radioactive cloud reaches the surface, forming a region of primary cloud fallout. There is consequently a continuous ring of water and spray between the cloud, if one has formed, and the surface of the water.

At about this time, the base surge has become detached from the bottom of the column, so that its ring-like character is apparent. The height of the base surge cloud is now 1,300 feet and its front, moving outward at some 75 feet per second (50 miles per hour), is about 1.2 miles from surface zero. Because of the radioactivity present in the base surge, the latter represents a hazard to personnel.

Several water waves have now developed, the first, with a height of 42 feet, being approximately 1 mile from surface zero.

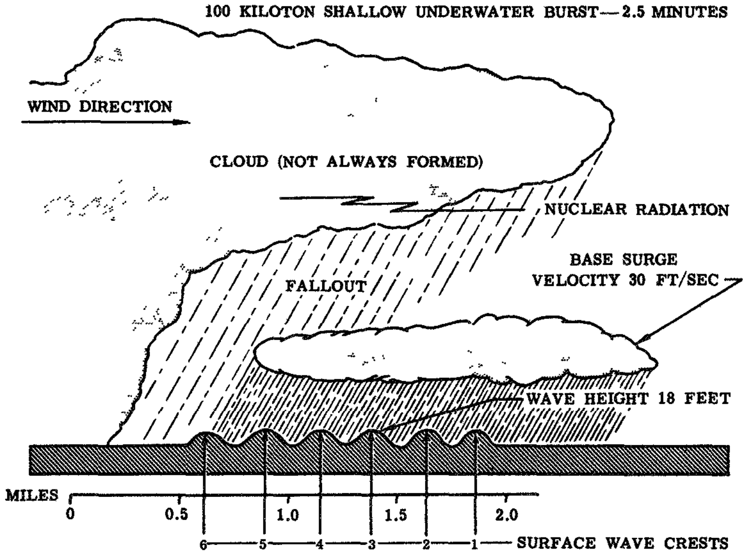


Figure 2.80e. Chronological development of a 100-kiloton shallow underwater burst: 2.5 minutes after detonation.

By 2½ minutes after the 100-kiloton underwater explosion, the front of the base surge is nearly 2 miles from ground zero and its height is roughly 2,000 feet. The effective spread of the visible base surge cloud at 4 minutes is approximately 2½ miles from surface zero, i.e., 5 miles across. The base surge now appears to be rising from the surface of the water. This effect is attributed to several factors, including an actual increase in altitude, thinning of the cloud by engulfing air, and raining out of the larger drops of water. Due to natural radioactive decay of the fission products, to rainout, and to dilution of the mist by air, the intensity of the nuclear radiation from the base surge at 2½ minutes after the explosion is only one-twentieth of that at 1 minute.

The descent of water and spray from the column and from condensation in the radioactive cloud results in the formation of a continuous mass of mist or cloud down to the surface of the water. Ultimately, this merges with the base surge, which has spread and increased in height, and also with the natural clouds of the sky, to be finally dispersed by the wind.

After 4 or 5 minutes, the visible base surge will begin to disappear as the water droplets evaporate. However, radioactive particles will still be present and will spread out in the form of the invisible base surge.

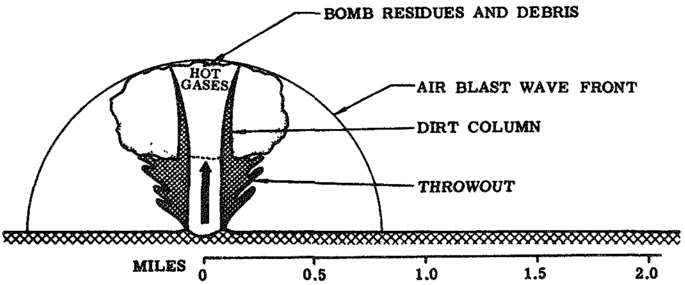

100 KILOTON SHALLOW UNDERGROUND BURST—2 SECONDS

Figure 2.93a. Chronological development of a 100-kiloton shallow underground burst: 2.0 seconds after detonation.

CHRONOLOGICAL DEVELOPMENT OF UNDERGROUND BURST

When a nuclear explosion occurs at a shallow depth underground, the fireball breaks through the surface of the earth within a fraction of a second of the instant of detonation. The intensely hot gases at high pressure are released and they carry up with them into the air large quantities of soil, rock, and debris in the form of a hollow column. For a burst at a shallow depth, the column tends to assume the shape of an inverted cone which fans out as it rises to produce a radial throw-out. A highly radioactive cloud, which contains large quantities of earth, is formed above the throw-out as the hot vapors cool and condense. Because of the mass displacement of material from the earth's surface, a crater is formed. For a 100-kiloton weapon exploding 50 feet beneath the surface of dry soil, the crater would be about 120 feet deep and 720 feet across. The weight of the material removed would be over a million tons.

In addition to the shock (or pressure) wave in the ground, somewhat related to an earthquake wave, the explosion is accompanied by a blast wave in the air. At 2 seconds after the explosion, the blast wave front in air is about ¾ mile from surface zero.

100 KILOTON SHALLOW UNDERGROUND BURST—9 SECONDS

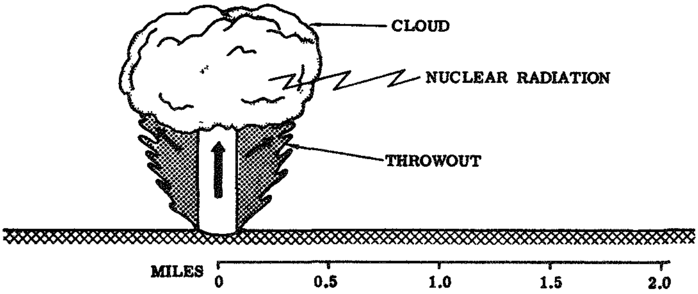


Figure 2.93b. Chronological development of a 100-kiloton shallow underground burst: 9.0 seconds after detonation.

The radioactive cloud continues to rise, giving off intense nuclear radiations which are still a hazard on the ground at 9 seconds after the detonation. At this time, the larger pieces of rock and debris in the throw-out begin to descend to earth.

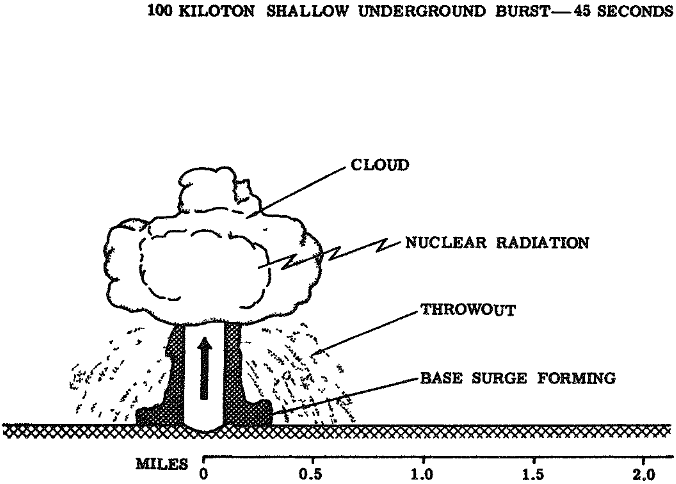


Figure 2 93c Chronological development of a 100-kiloton shallow underground burst: 45 seconds after detonation.

As the material from the column descends, the finer soil particles attain a high velocity and upon reaching the ground they spread out rapidly to form a base surge similar to that in an underwater explosion. The extent of the base surge, which is likely to be radioactive, depends upon many factors, including the energy yield of the explosion, the depth of burst, and the nature of the soil. It is believed that a dry sandy terrain would be particularly conducive to base surge formation.

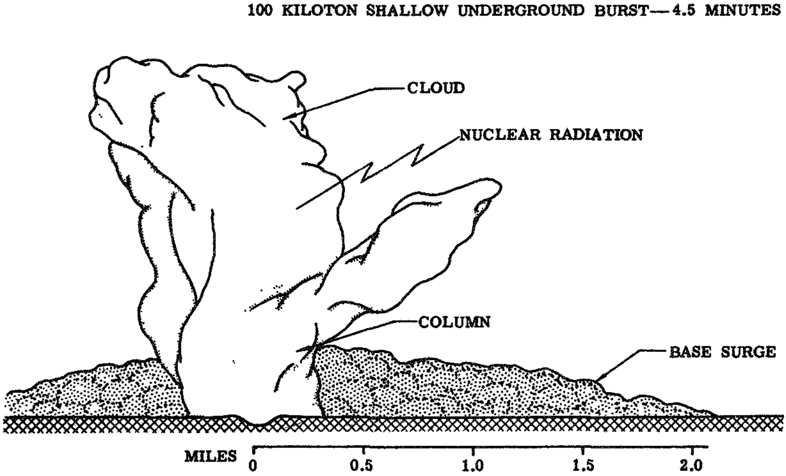


Figure 2.93d. Chronological development of a 100-kiloton shallow underground burst: 4.5 minutes after detonation.

The base surge increases in height and area and soon begins to merge with the radioactive cloud of weapon residues, etc., part of which descends and spreads out under the influence of the prevailing winds. In due course, the radioactive clouds disperse, but the contaminated particles descend to earth to produce a hazardous fallout over a large area, especially in the downwind direction, during the course of a few hours.

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*These documents may be obtained for a small charge from Office of Technical Services, U.S. Department of Commerce, Washington 25, D.C.

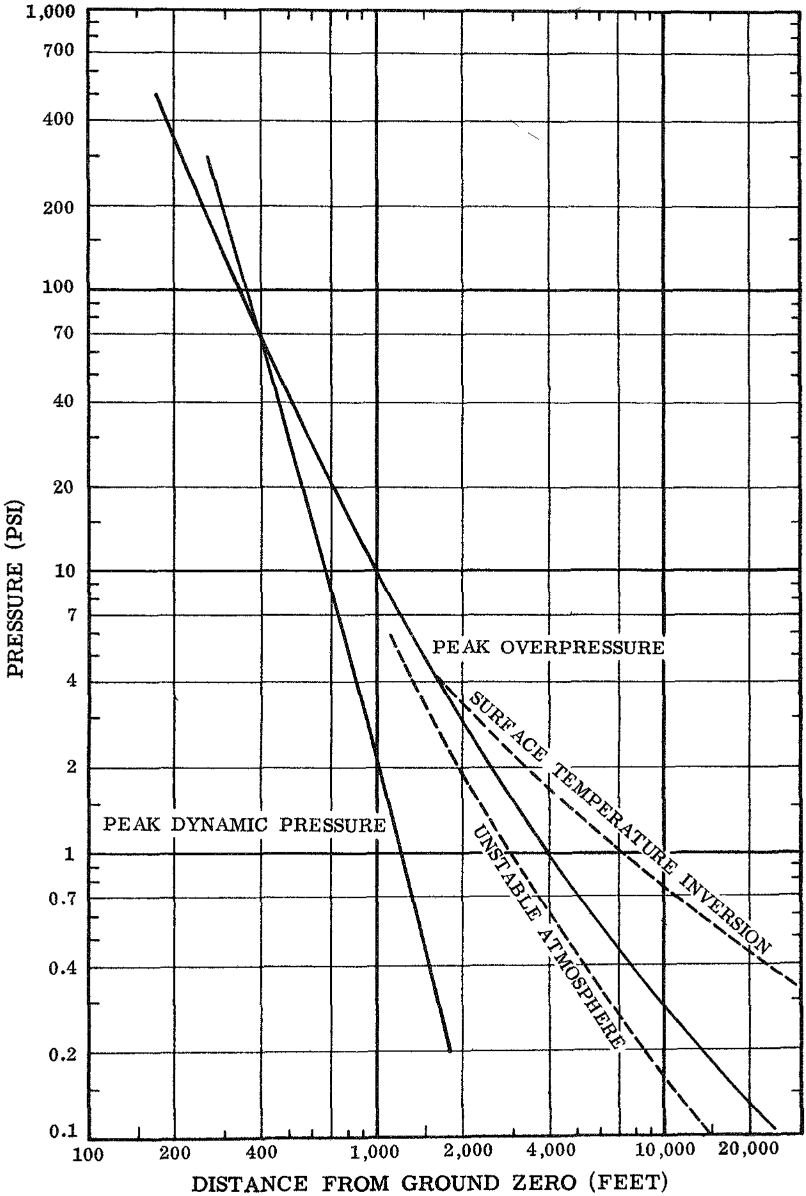

Figure 3.66. Peak overpressure and peak dynamic pressure for 1-kiloton surface burst.

TABLE 4.39

CONDITIONS OF FAILURE OF PEAK OVERPRESSURE-SENSITIVE ELEMENTS

Structural element	Failure	Approximate side-on blast overpressure
		psi
Glass windows, large and small	Shattering usually, occasional frame failure	0.5–1.0
Corrugated asbestos siding	Shattering	1.0–2.0
Corrugated steel or aluminum paneling	Connection failure followed by buckling	1.0–2.0
Brick wall panel, 8 in. or 12 in. thick (not reinforced).	Shearing and flexure failures	7.0–8.0
Wood siding panels, standard house constuction.	Usually failure occurs at the main connections allowing a whole panel to be blown in.	1.0–2.0
Concrete or cinder-block wall panels, 8 in. or 12 in. thick (not reinforced).	Shattering of the wall	2.0–3.0

be determined by the degree of protection from nuclear radiation required at the design overpressure or dynamic pressure (see Chapter VIII).

4.41 The usual method of providing earth cover for surface or "cut-and-cover" semiburied structures is to build an earth mound over the portion of the structure that is above the normal ground level. If the slope of the earth cover is chosen properly the blast reflection factor is reduced and the aerodynamic shape of the structure is improved. This results in a considerable reduction in the applied translational forces. An additional benefit of the earth cover is the stiffening or resistance to deformation that the earth provides to flexible structures by the buttressing action of the soil.

4.42 Light-weight, shallow buried underground structures are those constructed deep enough for the top of the earth cover to be flush with the original grade. However, they are not sufficiently deep for the ratio of the depth of burial to the span to be large enough for any benefit to be derived from soil arching (see § 4.44). For ratios of depth of burial to span between 0.25 and 3.0 in most soils, there is little attenuation of the air blast pressure applied to the top surface of a shallow buried underground structure. The results of full scale nuclear tests in Nevada indicate that there is apparently no increase in pressure exerted on the structure due to ground shock reflection at the interface between the earth and the top of the structure.

4.43 The lateral blast pressures exerted on the vertical faces of a shallow buried structure have been found to be as low as 15 percent of the blast pressure on the roof in dry, well-compacted, silty soils.

For most soils, however, this lateral blast pressure is likely to be somewhat higher and may approach 100 percent of the roof blast pressure in porous saturated soil. The pressures on the bottom of a buried structure, in which the bottom slab is a structural unit integral with the walls, may range from 75 to 100 percent of the pressure exerted on the roof.

4.44 Underground structures, buried at such a depth that the ratio of the burial depth to the span approaches (or exceeds) a value of 3.0, will obtain some benefit from the "arching effect" of the soil surrounding the structure. Limited experience at the Nevada Test Site has indicated that the arching action of the soil effectively reduces the loading on flexible structures, although the exact extent is at present uncertain.

4.45 The damage that might be suffered by a shallow buried structure will depend on a number of variables, including the structural characteristics, the nature of the soil, the depth of burial, and the downward pressure, i.e., the peak overpressure and direction of the blast wave. In Table 4.45 are given the limiting values of the peak overpressure required to cause various degrees of damage to two types of shallow buried structures. The range of pressures is intended to allow for differences in structural design, soil conditions, shape of earth mound, and orientation with respect to the blast wave.

4.46 An illustration of severe damage to a 10-gage corrugated steel-arch, earth-covered, surface structure is shown in Fig. 4.46. It

TABLE 4.45

DAMAGE CRITERIA FOR SHALLOW BURIED STRUCTURES

Type of structure	Damage type	Peak overpressure	Nature of damage
		psi	
Light, corrugated steel arch, surface structure (10-gage corrugated steel with a span of 20-25 ft), central angle of 180° with 5 ft of earth cover at the crown.*	Severe	45-60	Collapse.
	Moderate	40-50	Large deformations of end walls and arch, also major entrance door damage.
	Light	30-40	Damage to ventilation and entrance door.
Buried concrete arch with a 16 ft span and central angle of 180°; 8 in. thick with 4 ft of earth cover at the crown.	Severe	220-280	Collapse.
	Moderate	160-220	Large deformations with considerable cracking and spalling.
	Light	120-160	Cracking of panels, possible entrance door damge.

* In the case of arched structures reinforced with ribs, the collapse pressure is higher depending on the number of ribs.

Figure 4 46 Severe damage to earth-covered surface corrugated steel structure

will be noted that about half of the arch has collapsed This failure was attributed primarily to the dynamic pressure acting on the forward slope of the earth mound.

DAMAGE TO LAND TRANSPORTATION EQUIPMENT

4 47 The general types of land transportation equipment considered here include civilian motor-driven vehicles and earth-moving

the usual destruction of doors and windows. The steel window-sash remained in place but was distorted, and some spalling of the concrete around lug connections was noted. On the whole, the damage to the house was of a minor character and it could readily have been repaired.

Trailer-Coach Mobile Homes

5.45 Sixteen trailer coaches of various makes, intended for use as mobile homes, were subjected to blast in the 1955 test. Trailer parks and dealer stocks are generally situated at the outskirts of cities, and so the mobile homes to be tested were placed at a considerable distance from ground zero. Nine trailer-coach mobile homes were located where the peak blast overpressure was 1.7 pounds per square inch, and the other seven where the overpressure was about 1 pound per square inch. They were parked at various angles with respect to the direction of travel of the blast wave.

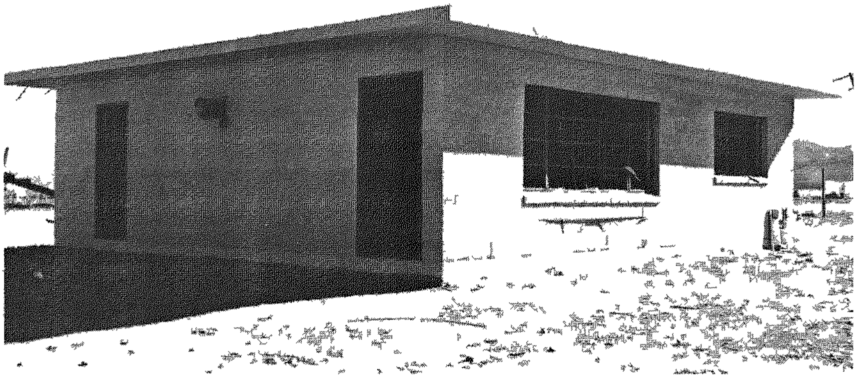

Figure 5 42 Reinforced masonry-block house after a nuclear explosion (5 psi overpressure)

5.46 At the higher overpressure two of the mobile homes were tipped over by the explosion. One of these was originally broadside

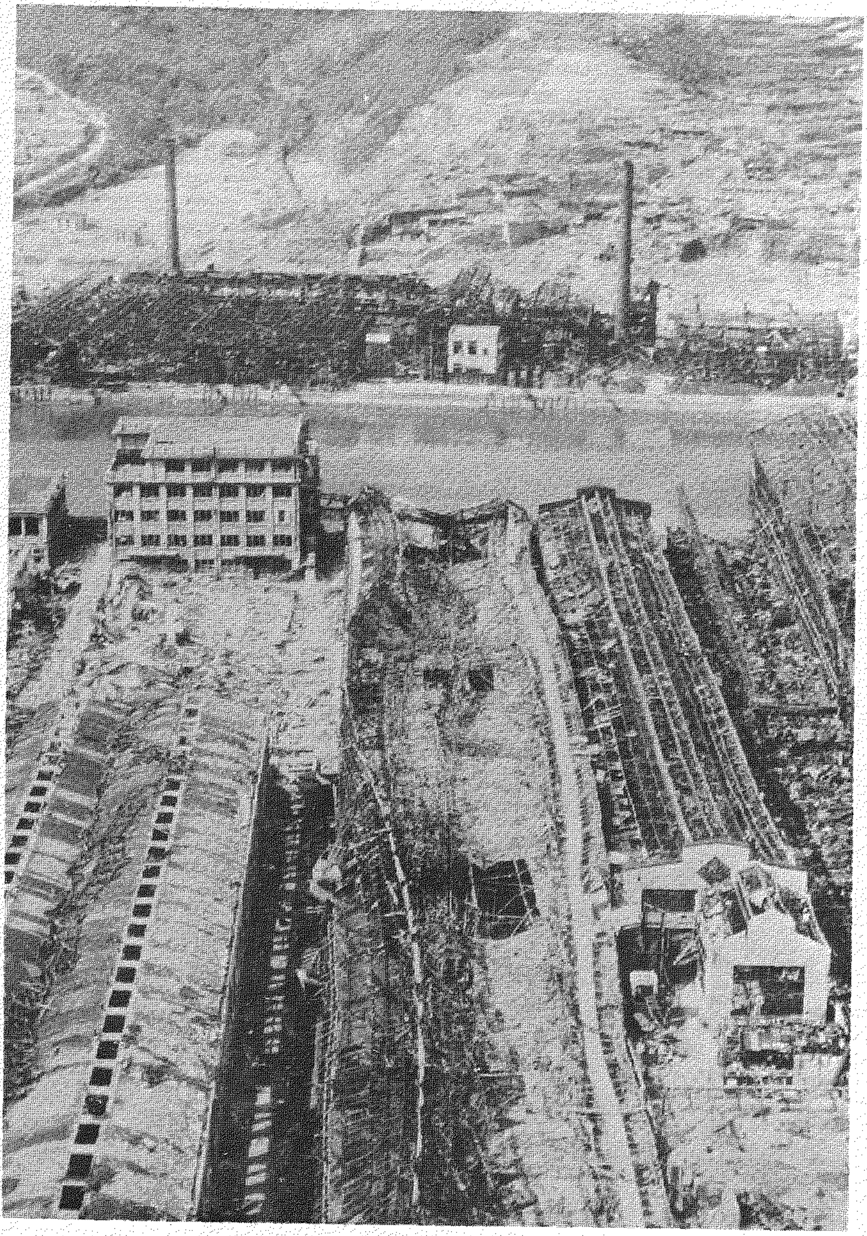

Figure 5.91. At left and back of center is a multistory, steel-frame building (0.85 mile from ground zero at Nagasaki).

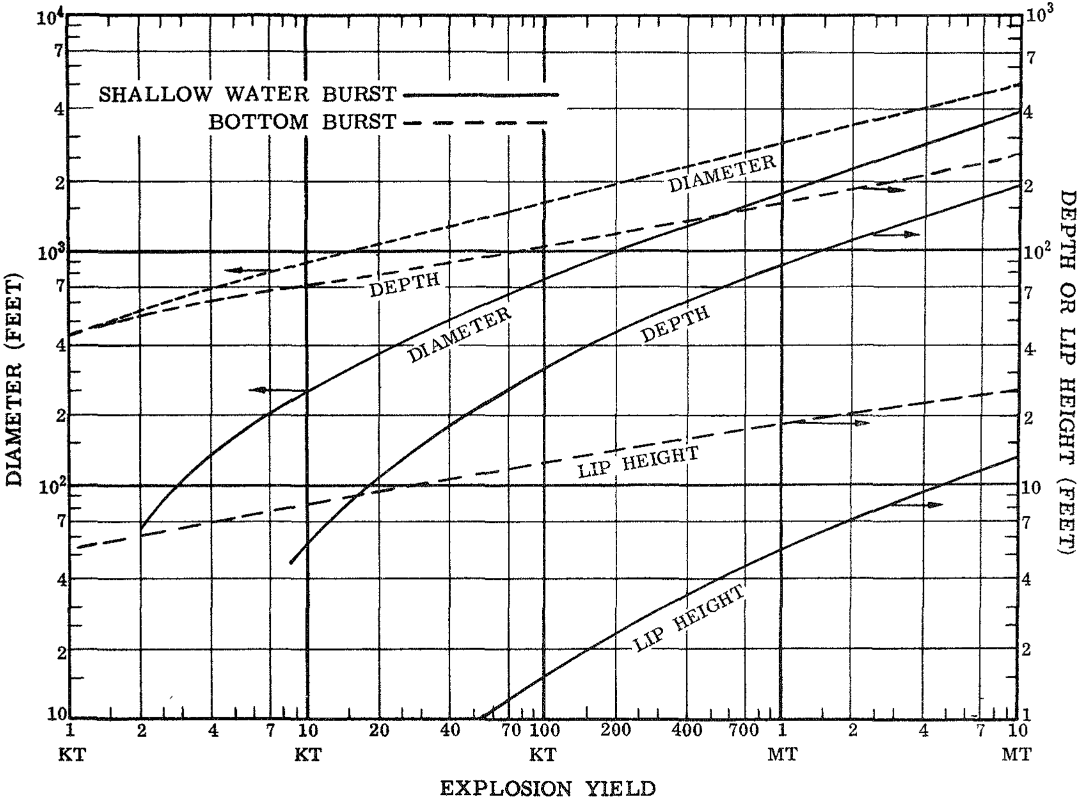

Figure 6.81. Dimensions of crater in underwater bursts as a function of explosion yield.

ignitions may be started in newspaper as a direct result of the absorption of thermal radiation. Under hazy atmospheric conditions, or in the event of a surface burst, the distances obtained from Fig. 7.47 may be decreased. Similarly, in accordance with discussion in § 7.21 *et seq.*, a layer of dense cloud or smoke between the target and the point of burst will decrease the distance over which ignitions may occur.

THERMAL EFFECTS ON MATERIALS IN JAPAN[3]

7.48 Apart from the actual ignition of combustible materials resulting in fires being started, which will be referred to later, a number of other phenomena observed in Japan testified to the intense heat due to the absorption of thermal radiation. Fabrics (Fig. 7.48a), utility poles (Fig. 7.48b), trees, and wooden posts, up to a radius of 11,000 feet (2.1 miles) from ground zero at Nagasaki, and 9,000 feet

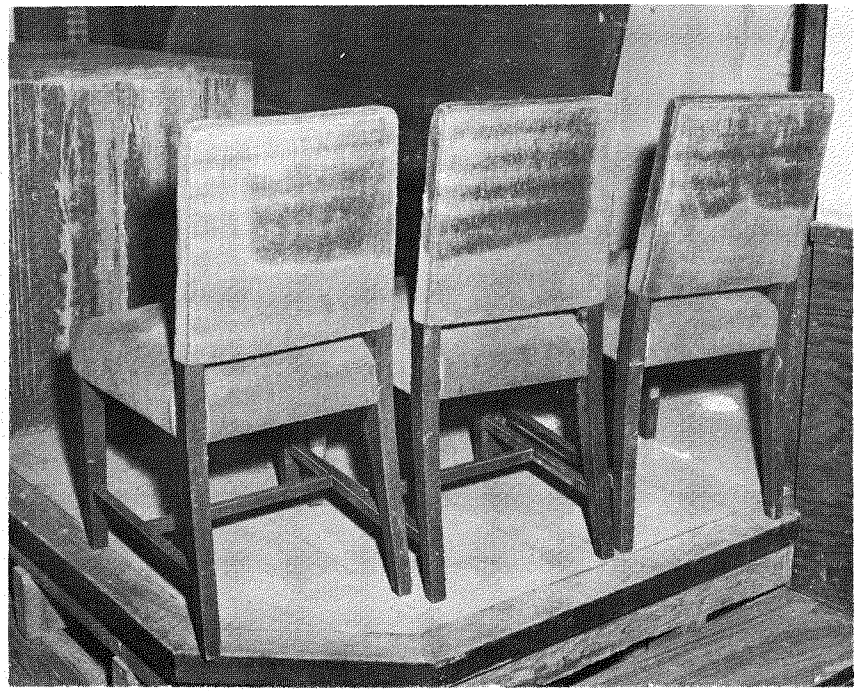

Figure 7.48a. Flash burns on upholstery of chairs exposed to bomb flash at window (1 mile from ground zero at Hiroshima).

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[3] The effects of thermal radiations on human beings in Japan are described in Chapter XI.

INCENDIARY EFFECTS

ORIGIN OF FIRES

7.54 There are two general ways in which fires can originate in a nuclear explosion. First, by the ignition of paper, trash, window curtains, awnings, excelsior, dry grass, and leaves, as a direct result of the absorption of thermal radiation. And second, as an indirect effect of the destruction caused by the blast wave, fires can be started by upset stoves and furnaces, electrical short-circuits, and broken gas lines. No matter how the fire originates, its subsequent spread will be determined by the amount and distribution of combustible materials in the vicinity. The manner whereby fires in cities grow and spread from ignition points is a complex matter which will be discussed later. In the meantime, two aspects of the problem of the development of fires accompanying a nuclear explosion will be considered, namely, (1) the number of points at which fires originate, and (2) the character of the surrounding area.

7.55 The initiation of secondary (or indirect) fires is difficult to analyze, but there are some aspects of direct ignition by thermal radiation which are reasonably clear. The most important appears to be what has been called the "density of ignition points." This is the number of points in a given area, e.g., an acre, where exterior combustible materials are present which will produce a primary ignition and may result in a fire. In general, these materials may be expected to ignite when exposed to at least the appropriate radiant energy values given in Tables 7.40 and 7.44. The data in Fig. 7.55 are based on surveys made in a number of large cities in the United States. It is seen that the density of ignition points is greatest in wholesale distribution and slum residential areas, and is least in good residential and large manufacturing areas.[4] Paper was the commonest ignitable material found everywhere except in downtown retail areas where awnings represented the major source of fire.

7.56 The density of ignition points provides some indication of the chance of fires being started under ideal weather conditions. But the results in Fig. 7.55 are by themselves not sufficient to permit an estimate to be made of the number of significant fires that will actually result. In the first place, at locations closer to ground zero where moderate to severe blast damage occurs, almost all ignitable materials will constitute a fire hazard. On the other hand, at greater distances, only those most easily ignitable will catch fire. Further,

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[4] The area types are in accordance with the classification used by the U.S. Bureau of Census.

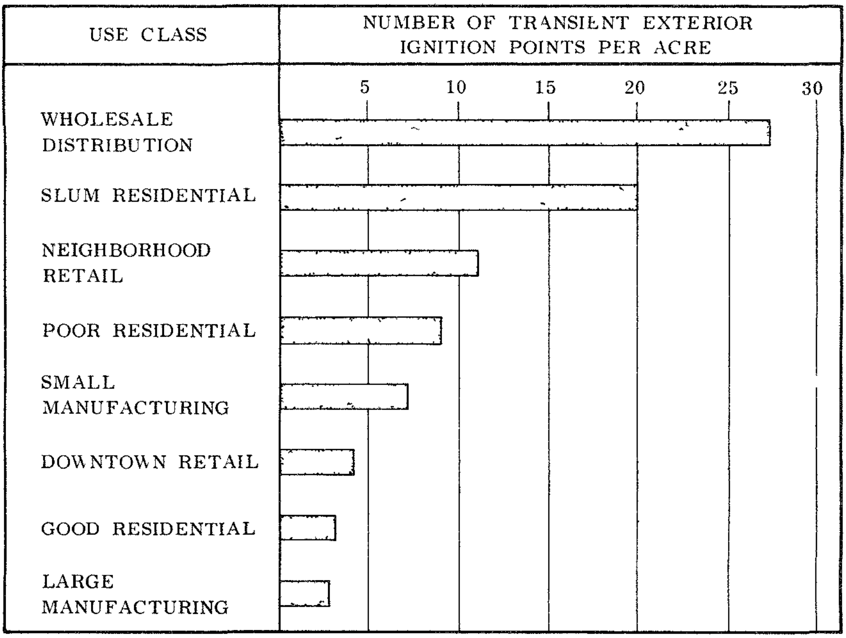

Figure 7.55 Frequency of exterior ignition points for various areas in a city

the formation of a significant fire, capable of spreading, will require appreciable quantities of combustible material close by, and this may not always be available.

7.57 The fact that accumulations of ignitable trash close to a wooden structure represent a real fire hazard was demonstrated at the nuclear tests carried out in Nevada in 1953. In these tests, three miniature wooden houses, each having a yard enclosed with a wooden fence, were exposed to 12 calories per square centimeter of thermal radiation. One house, at the left of Fig. 7.57, had weathered siding showing considerable decay, but the yard was free from trash. The next house also had a clean yard and in addition, the exterior siding was well maintained and painted. In the third house, at the right of the photograph, the siding, which was poorly maintained, was weathered, and the yard was littered with trash.

7.58 The state of the three houses after the explosion is seen in Fig. 7.58. The third house, at the right, soon burst into flame and was burned to the ground. The first house, on the left, did ignite but it did not burst into flame for 15 minutes. The well maintained house in the center with the clean yard suffered scorching only. It is of interest to recall that the wood of a newly erected white-painted

Figure 7.57 Wooden test houses before exposure to a nuclear explosion, Nevada Test Site

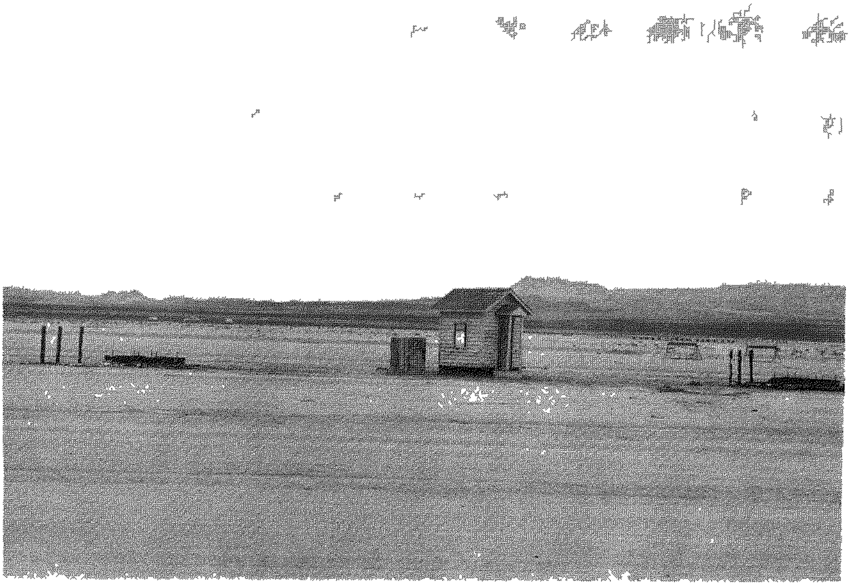

Figure 7.58 Wooden test houses after exposure to a nuclear explosion

house exposed to about 25 calories per square centimeter was badly charred but did not ignite (see Fig. 7.33b).

7.59 The value of fire-resistive furnishing in decreasing the number of ignition points was also demonstrated in the tests. Two identical, sturdily constructed houses, each having a window 4 feet by 6 feet facing the point of burst, were erected where the thermal radiation exposure was 17 calories per square centimeter. One of the houses contained rayon drapery, cotton rugs, and clothing, and, as was expected, it burst into flame immediately after the explosion and burned completely. In the other house, the draperies were of vinyl plastic, and rugs and clothing were made of wool. Although much ignition occurred, the recovery party, entering an hour after the explosion, was able to extinguish the fires.

7.60 There is another point in connection with the initiation of fires by thermal radiation that needs consideration. This is the possibility that the flame resulting from the ignition of a combustible material may be subsequently extinguished by the blast wind. It was thought that there was evidence for such an effect from an observation made in Japan (§ 7.67), but this may have been an exceptional case. The matter has been studied, both in connection with the effects in Japan and at various nuclear tests, and the general conclusion is that the blast wind has no significant effect in extinguishing fires (§ 7.68).

SPREAD OF FIRES

7.61 The spread of fires in a city, including the development of a "fire storm" to which reference is made in § 7.75, depends upon a variety of conditions, e.g., weather, terrain, and closeness and combustibility of the buildings. Information concerning the growth and spread of fires from a large number of ignition points, such as might follow a nuclear explosion, and their coalescence into large fires (or conflagrations) is limited to the experience of World War II incendiary raids and the two atomic bomb attacks. There is consequently some uncertainty concerning the validity of extrapolating from these limited experiences to the behavior to be expected in other cities. It appears, however, that if other circumstances are more-or-less the same, an important criterion of the probability of fire spread is the distance between buildings. It is evident, from general considerations, that the lower the building density or "built-upness" of an area, the less will be the probability that fire will spread from one structure to another. Furthermore, the larger the spaces between buildings the greater the chances that the fire can be extinguished.

7.62 The curve in Fig. 7.62 gives a rough idea of how the probability of fire spread, expressed as a percentage, depends upon the average distance between buildings in a city. The results will be dependent, to some extent, upon the types of structures involved, e.g., whether they are fire-resistive or not, as well as upon the damage caused by the blast wave. It should be noted that Fig. 7.62 applies to fire spread accompanying a nuclear explosion, when a large number of small fires are started directly by thermal radiation and indirectly in other ways.

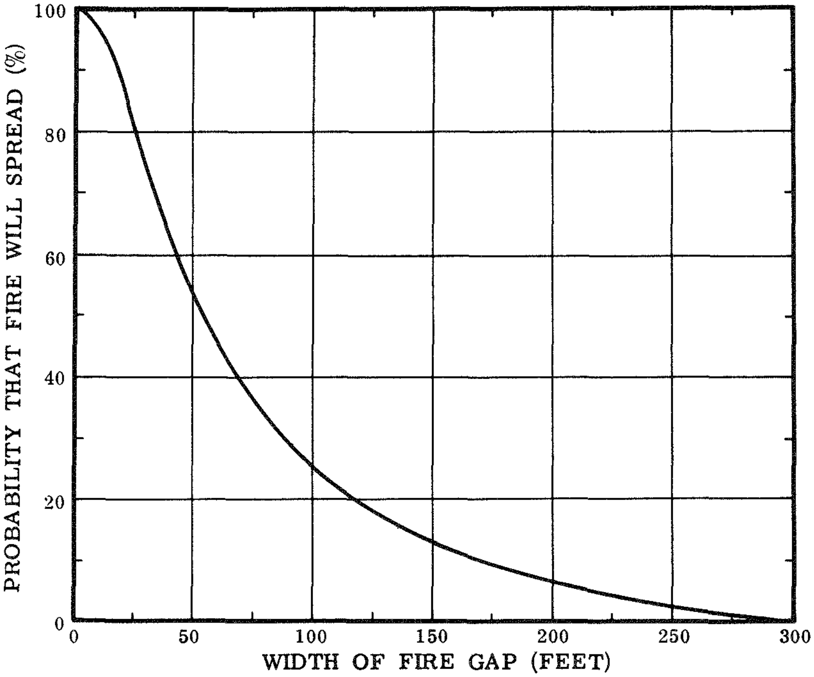

Figure 7.62. Width of gap and probability of fire spread.

7.63 Another aspect of fire spread is the development of mass fires in a forest following primary ignition of dried leaves, grass, and rotten wood by the thermal radiation. Some of the factors which will influence the growth of such fires are the moisture content of the trees, topography, and meteorological conditions. Low atmospheric humidity, strong winds, and steep terrain favor the development of forest fires. In general, a deciduous forest, particularly when in leaf, may be expected to burn less rapidly and with less intensity than a forest of coniferous trees. Green leaves and the trunks of trees would act as shields against thermal radiation, so that the number of points at which ignition occurs in a forest may well be less than would appear at first sight.

INCENDIARY EFFECTS IN JAPAN

THE NUCLEAR BOMB AS AN INCENDIARY WEAPON

7.64 The incendiary effects of a nuclear explosion do not present any especially characteristic features. In principle, the same overall result, as regards destruction by fire and blast, might be achieved by the use of conventional incendiary and high-explosive bombs. It has been estimated, for example, that the fire damage to buildings and other structures suffered at Hiroshima could have been produced by about 1,000 tons of incendiary bombs distributed over the city. It can be seen, however, that since this damage was caused by a single nuclear bomb of only 20 kilotons energy yield, nuclear weapons are capable of causing tremendous destruction by fire, as well as by blast.

7.65 Evidence was obtained from the nuclear explosions over Japan that the damage by fire is much more dependent upon local terrain and meteorological conditions than are blast effects. At both Hiroshima and Nagasaki the distances from ground zero at which particular types of blast damage were experienced were much the same. But the ranges of incendiary effects were quite different. In Hiroshima, for example, the total area severely damaged by fire, about 4.4 square miles, was roughly four times as great as in Nagasaki. One contributory cause was the irregular layout of Nagasaki as compared with Hiroshima; also greater destruction could probably have been achieved by a change in the point of burst. Nevertheless, an important factor was the difference in terrain, with its associated building density. Hiroshima was relatively flat and highly built up, whereas Nagasaki had hilly portions near ground zero that were bare of structures.

ORIGIN AND SPREAD OF FIRES IN JAPAN

7.66 Definite evidence was obtained from Japanese observers that the thermal radiation caused thin, dark cotton cloth, such as the black-out curtains that were in common use during the war, thin paper, and dry, rotted wood to catch fire at distance up to 3,500 feet (0.66 mile) from ground zero (about 35 calories per square centimeter). It was reported that a cedar bark roof farther out was seen to burst into flame, apparently spontaneously, but this was not definitely confirmed. Abnormal enhanced amounts of radiation, due to re-

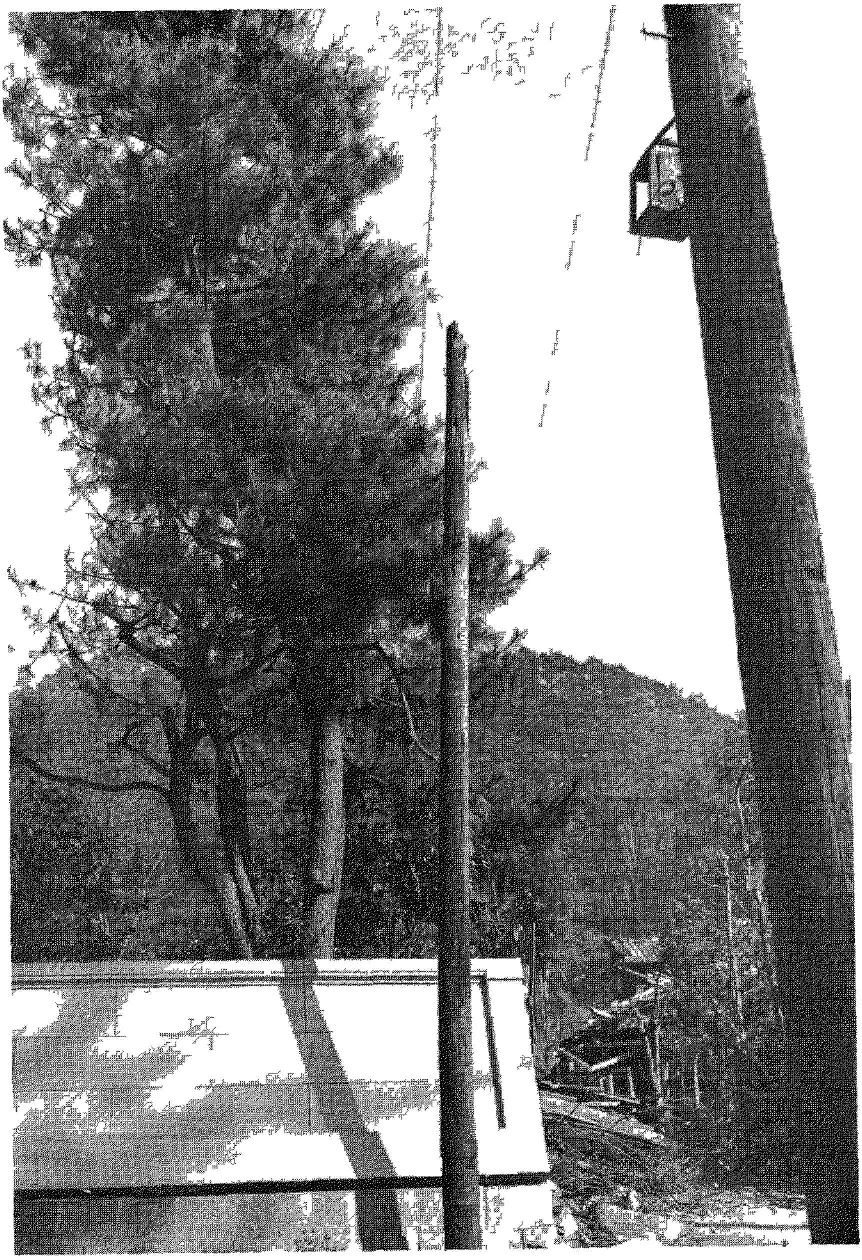

Figure 7 66 The top of a wood pole was reported as being ignited by the thermal radiation (1 25 miles from ground zero at Hiroshima) Note the unburned surroundings, the nearest burned building was 360 feet away flection, scattering, and focusing effects, might have caused fires to originate at isolated points (Fig. 7.66).

7.67 Interesting evidence of the ignition of sound wood was found about a mile from ground zero at Nagasaki, where the radiant exposure was approximately 15 calories per square centimeter. A light piece of wood, similar to the flat side of an orange crate, had its front surface charred. In addition, however, blackening was observed through cracks and nail holes, where the thermal radiation would not have penetrated, and also around the edges adjoining the charred surface. A possible explanation is that the exposed surface of the wood had actually ignited, due to the heat from the thermal radiation, and the flames had spread through the cracks and holes around the edges for several seconds, before they were extinguished by the blast wind.

7.68 From the evidence of charred wood found at both Hiroshima and Nagasaki, it was originally concluded that such wood had actually been ignited by thermal radiation and that the flames were subsequently extinguished by the blast. But it now seems more probable that, apart from some exceptional instances, such as that just described, there was no actual ignition of the wood. The absorption of the thermal radiation caused charring in sound wood but the temperatures were generally not high enough for ignition to occur (§ 7.33). Rotted and checked wood and excelsior, however, have been observed to burn completely, and the flame was not greatly affected by the blast wave.

7.69 It is not known to what extent thermal radiation contributed to the initiation of fires in the nuclear bombings in Japan. It is possible that, up to a mile or so from ground zero, some fires may have originated from secondary causes, such as upsetting of stoves, electrical short-circuits, broken gas lines, and so on, which were a direct effect of the blast wave. A number of fires in industrial plants were initiated by furnaces and boilers being overturned, and by the collapse of buildings on them.

7.70 Once the fires had started, there were several factors, directly related to the destruction caused by the nuclear explosion, that influenced their spreading. By breaking windows and blowing in or damaging fire shutters (Fig. 7.70), by stripping wall and roof sheathing, and collapsing walls and roofs, the blast made many buildings more vulnerable to fire. Noncombustible (fire-resistive) structures were often left in a condition favorable to the internal spread of fires by damage at stairways, elevators, and in firewall openings as well as by the rupture and collapse of floors and partitions (see Fig. 5.89d).

7.71 On the other hand, when combustible frame buildings were blown down, they did not burn as rapidly as they would have done had they remained standing. Moreover, the noncombustible debris produced by the blast frequently covered and prevented the burning of combustible material. There is some doubt, therefore, whether on the whole the effect of the blast was to facilitate or to hinder the development of fires at Hiroshima and Nagasaki.

Figure 7.70. Fire shutters in building blown in or damaged by the blast; shutter at center probably blown outward by blast passing through building (0.57 mile from ground zero at Hiroshima).

7.72 Although there were firebreaks, both natural, e.g., rivers and open spaces, and artificial, e.g., roads and cleared areas, in the Japanese cities, they were not very effective in preventing the fires from spreading. The reason was that fires often started simultaneously on both sides of the firebreaks, so that they could not serve their intended purpose. In addition, combustible materials were frequently strewn across the firebreaks and open spaces, such as yards and street areas, by the blast, so that they could not prevent the spread of fires. Nevertheless, there were a few instances where firebreaks assisted in preventing the burnout of some fire-resistive buildings.

7.73 One of the important aspects of the nuclear attacks on Japan was that, in the large area that suffered simultaneous blast damage, the fire departments were completely overwhelmed. It is true that the fire-fighting services and equipment were poor by American standards, but it is doubtful if much could have been achieved, under the circumstances, by more efficient fire departments. At Hiroshima, for example, 70 percent of the fire-fighting equipment was crushed in the collapse of fire houses, and 80 percent of the personnel were unable to respond. Even if men and machines had survived the blast, many fires would have been inaccessible because of the streets being blocked with debris. For this reason, and also because of the fear of being trapped, a fire company from an area which had escaped destruction was unable to approach closer than 6,600 feet (1.25 miles) from ground zero at Nagasaki. It was almost inevitable, therefore, that all buildings within this range would be destroyed.

7.74 Another contributory factor to the destruction by fire was the failure of the water supply in both Hiroshima and Nagasaki. The pumping stations were not largely affected, but serious damage was sustained by distribution pipes and mains, with a resulting leakage and drop in available water pressure. Most of the lines above ground were broken by collapsing buildings and by heat from the fires which melted the pipes. Some buried water mains were fractured and others were broken due to the collapse or distortion of bridges upon which they were supported (§ 5.117).

FIRE STORM IN HIROSHIMA

7.75 About 20 minutes after the detonation of the nuclear bomb at Hiroshima, there developed the phenomenon known as "fire storm." This consisted of a wind which blew toward the burning area of the city from all directions, reaching a maximum velocity of 30 to 40 miles per hour about 2 to 3 hours after the explosion, decreasing to light or moderate and variable in direction about 6 hours after. The wind was accompanied by intermittent rain, light over the center of the city and heavier about 3,500 to 5,000 feet (0.67 to 0.95 mile) to the north and west. Rain is often associated with a fire storm and is apparently due to the condensation of moisture on particles from the fire when they reach a cooler area. Because of the strong inward draft at ground level, the fire storm was a decisive factor in limiting the spread of fire beyond the initial ignited area. It accounts for the fact that the radius of the burned-out area was so uniform in Hiroshima and was not much greater than the range in which fires started soon after the explosion. However, virtually everything combustible within this region was destroyed.

7.76 It should be noted that the fire storm is by no means a special characteristic of nuclear weapons. Similar fire storms have been reported as accompanying large forest fires in the United States, and especially after incendiary bomb attacks in both Germany and Japan during World War II. The high winds are produced largely by the updraft of the heated air over an extensive burning area. They are thus the equivalent, on a very large scale, of the draft of a chimney under which a fire is burning. Because of limited experience, the conditions for the development of fire storms in cities are not well known. It appears, however, that some, although not necessarily all, of the essential requirements are the following: (1) thousands of nearly simultaneous ignitions over an area of at least a square mile, (2) heavy building density, e.g., more than 20 percent of the area is covered by buildings, and (3) little or no ground wind. Based on these criteria, only certain sections—usually the older and slum areas—of a very few cities in the United States would be susceptible to fire storm development.

7.77 It should be mentioned that no definite fire storm occurred at Nagasaki, although the velocity of the southwest wind, blowing between the hills, increased to 35 miles an hour when the conflagration had become well established, perhaps about 2 hours after the explosion. This wind tended to carry the fire up the valley in a direction where there was nothing to burn. Some 7 hours later, the wind had shifted to the east and its velocity had dropped to 10 to 15 miles per hour. These winds undoubtedly restricted the spread of fire in the respective directions from which they were blowing. The small number of dwellings exposed in the long narrow valley running through Nagasaki probably did not furnish sufficient fuel for the development of a fire storm as compared to the many buildings on the flat terrain at Hiroshima.

TECHNICAL ASPECTS OF THERMAL RADIATION [5]

DISTRIBUTION AND ABSORPTION OF ENERGY FROM THE FIREBALL

7.78 Spectroscopic studies made in the course of weapons tests have shown that the fireball does not behave exactly like a black body, i.e., as a perfect radiator. Generally, the proportion of radiations of longer wave length (greater than 5,500 A)[6] corresponds to higher black body temperatures than does the shorter wave emission. The assumption of black body behavior for the fireball, however, serves as a reasonable approximation in interpreting the thermal

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[5] The remaining sections of this chapter may be omitted without loss of continuity.

[6] The symbol "A" represents the "angstrom", i.e., 10^{-8} cm, the unit in which radiation wave lengths are commonly expressed.

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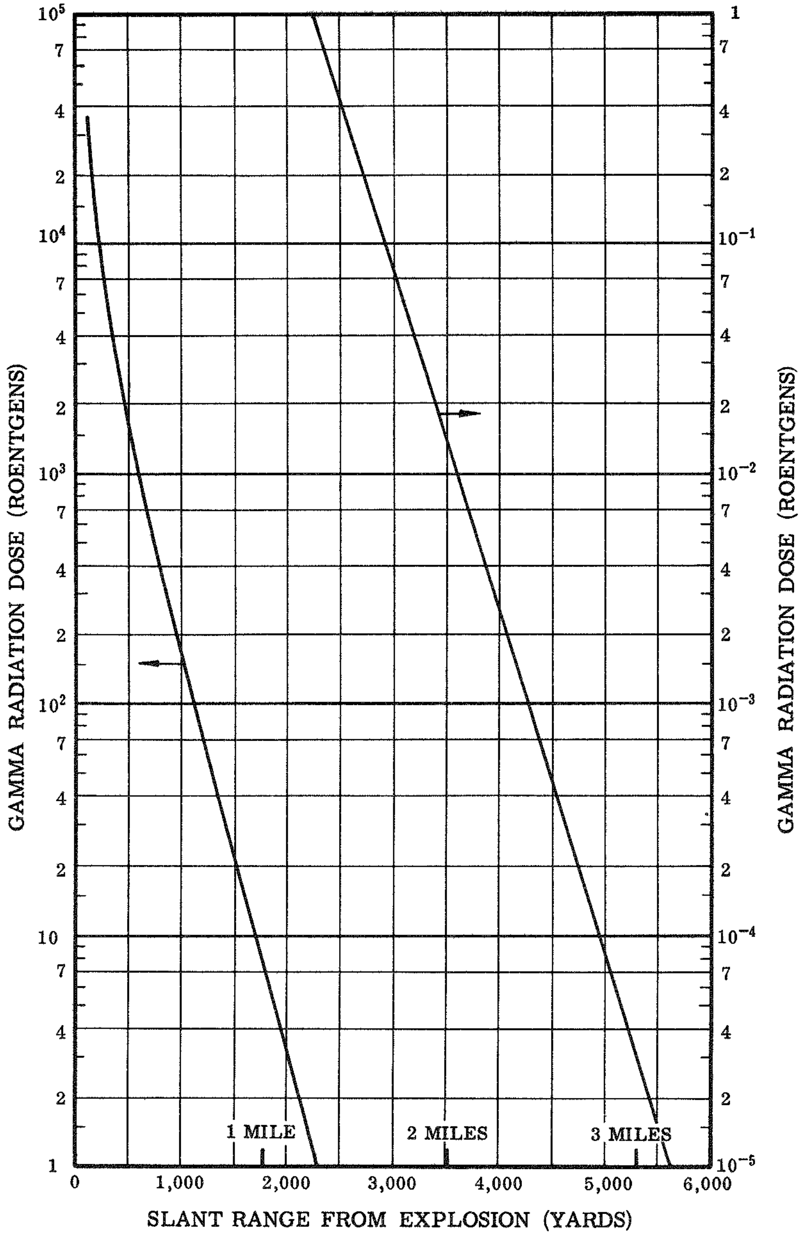

Figure 8.27a. Initial gamma-radiation dose as function of slant range from explosion for 1-kiloton air burst, based on 0.9 sea-level air density.

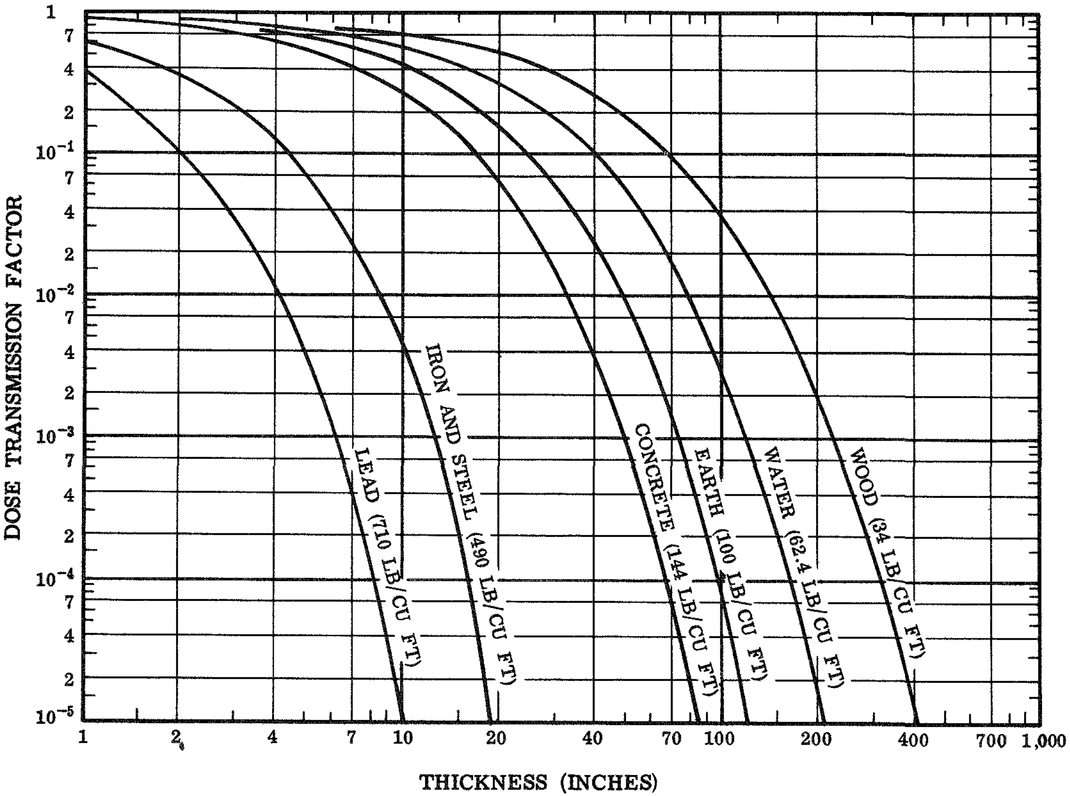

Figure 8.38. Dose transmission factors for initial gamma radiations of various materials as function of thickness.

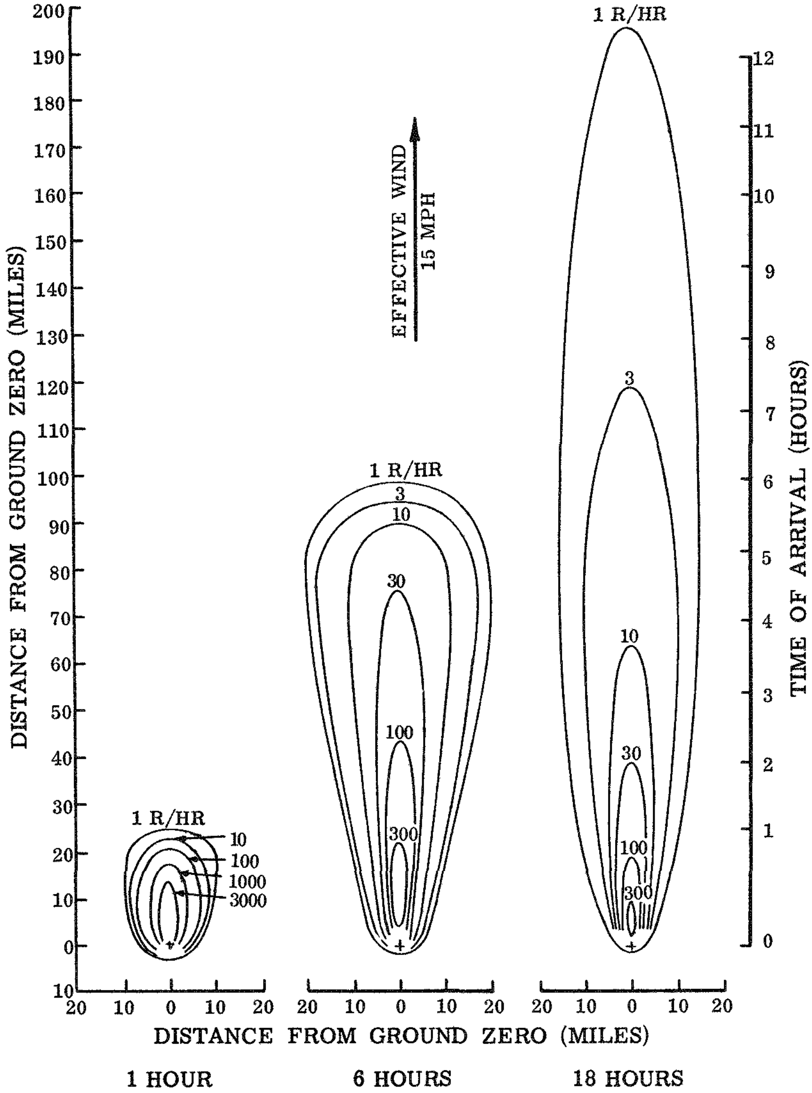

Figure 9.67a. Dose-rate contours from early fallout at 1, 6, and 18 hours after a surface burst with 1-megaton fission yield (15 mph effective wind speed).

then decay to about 300 r/hr at 6 hours. At 18 hours it is down to roughly 80 roentgens per hour. The increase in dose rate from 1 to 6 hours means that at the specified location the fallout was not complete at 1 hour after the detonation. The decrease from 6 to 18 hours

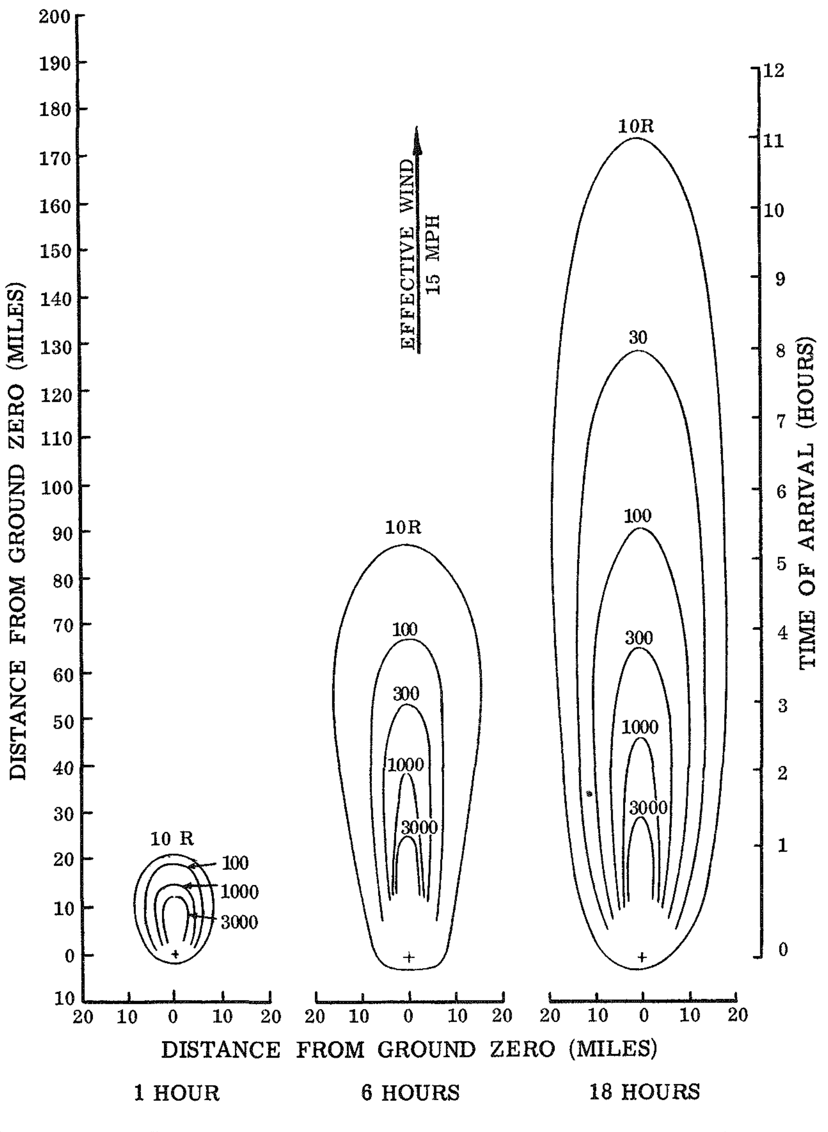

Figure 9.67b. Total-dose contours from early fallout at 1, 6, and 18 hours after surface burst with 1-megaton fission yield (15 mph effective wind speed).

is then due to the natural decay of the fission products. Turning to Fig. 9.67b, it is seen that the total radiation dose received at the given location by 1 hour after the explosion is small, because the fallout has only just started to arrive. By 6 hours, the total dose has

TABLE 9.139

PROTECTION FACTOR RANGES FOR VARIOUS STRUCTURES

Type of structure	*Protection factor range*
Underground shelters (3 ft earth cover or equivalent). Sub-basements of multistory buildings.*	1,000 or greater
Basement fallout shelters (heavy masonry residences). Basements without exposed walls of multistory masonry buildings. Central areas of upper floors (excluding top 3 floors) of high-rise buildings † with heavy floors and exterior walls.	250 to 1,000
Basement fallout shelters (frame and brick veneer residences). Central areas of basements with partially exposed walls in multistory buildings. Central areas of upper floors (excluding top floor) of multistory buildings with heavy floors and exterior walls.	50 to 250
Basements without exposed walls of small 1- or 2-story buildings. Central areas of upper floors (excluding top floor) of multistory buildings with light floors and exterior walls.	10 to 50
Basements (partially exposed) of small 1- or 2-story buildings. Central areas on ground floor in 1- or 2-story buildings with heavy masonry walls.	2 to 10
Above ground areas of light residential structures.	2 or less

* Multistory buildings are those having from 3 to about 10 stories.
† High-rise buildings have more than about 10 stories.

arises from the possible exposure to gamma rays from sources outside the body, with the effect of beta particles from fallout material in direct contact with the skin as secondary. Because most of the radioisotopes in the early fallout have relatively short half-lives, the activity decays fairly rapidly and will have decreased by a factor of several thousand after 6 months (or less). The delayed fallout hazard, on the other hand, is due to radioactive material, particularly strontium-90, which is ingested as food. The strontium-90 accumulates in the bone and part may remain there for many years, representing a prolonged internal hazard. Both early and delayed fallout can have long-term genetic effects, but they are probably of less significance than other deleterious effects to be expected. These and related aspects of fallout are discussed more fully in Chapter XI.

9.142 The very fine particles present in the radioactive cloud, with radii of a few microns or less (§ 9.47), fall extremely slowly under the influence of gravity. Consequently, they remain suspended in the

CHAPTER X

RADIO AND RADAR EFFECTS

INTRODUCTION

10.01 A nuclear explosion is accompanied by two principal types of electromagnetic effects.[1] These are entirely different from each other in nature, but both involve the whole spectral region of wavelengths longer than infrared, i.e., from about 1 millimeter on up to very large values. One involves the actual emission of an electromagnetic pulse of short duration from the explosion itself (or from the disturbed region in its vicinity), whereas the other, through alterations to the electrical properties of the atmosphere, can result in serious disturbance of electromagnetic waves, such as are used in communications and for radar, passing in the vicinity of the nuclear detonation. This disturbance may be caused by debris or water vapor introduced into the atmosphere by the burst, or by the unusual conditions created by the ionizing radiations from the exploding device. The latter mechanism may cause some radio and radar systems to be "blacked out" for several hours following the explosion. What little is known about the origin and characteristics of the electromagnetic pulse will be described first; the bulk of this chapter will then be concerned with a discussion of the changes in the normal ionization of the atmosphere brought about by a nuclear explosion and of the consequences of these changes.

THE ELECTROMAGNETIC PULSE

Origin of the Electromagnetic Pulse

10.02 The electromagnetic pulse or "radioflash" which is produced at the time of a nuclear detonation is of considerable interest. It is fairly well known that even small detonations of ordinary chemical

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[1] The term "electromagnetic" as used in this chapter applies to radiations of the longer wavelengths and not to the entire spectrum described in § 1.69 *et seq.*, which is strictly included in the term.

explosives can produce electromagnetic signals, so it is not surprising that substantial pulses of this type accompany nuclear explosions.

10.03 There appear to be at least two different mechanisms whereby an electromagnetic pulse may be produced by a nuclear explosion. The first is associated with the creation by radiations from the burst of some kind of asymmetry in the electric charge distribution in the region surrounding the detonation; the second is the result of the rapid expansion of the essentially perfectly-conducting plasma of weapon residues in the earth's magnetic field. The first mechanism, often called the "Compton-electron model" for reasons which will be seen below, is believed to be the principal means for generation of electromagnetic pulses by detonations on or slightly above the earth's surface and by those near the "top" of the sensible atmosphere. The other, called the "field displacement" model, might be responsible for electromagnetic signals from underground bursts where the expansion is restrained in a more or less spherically symmetrical manner by the surrounding material, or from those at such great altitudes that the only immediate interaction of the explosion is with the geomagnetic field.

10.04 In the Compton-electron model the photons of the initial gamma radiation leave the exploding weapon with high energies, very soon collide with electrons in the atoms and molecules of the surrounding air, and transfer to them most of their energy. These Compton electrons (§ 8.68) move rapidly away, on the average, from the center of the burst. Provided some kind of asymmetry exists, this motion is apparently one of the main sources of the electromagnetic pulse. If the explosion were perfectly symmetrical, in a uniform atmosphere, the effects would be equal in all directions; the opposite components would then compensate each other exactly and there would be no electromagnetic signal. However, there are invariably a number of unrelated factors associated with a nuclear explosion which insures the presence of an asymmetry and, hence, of an electromagnetic pulse.

10.05 The most obvious asymmetric situation is that arising from a surface or near-surface (within 350 feet or so) burst, where the presence of the earth itself confines expansion of the weapon residues and radiation emission to the upward hemisphere. At the other extreme, where the explosion takes place high in the atmosphere, there will be very little interaction by upward-moving gamma rays because of the low air density, whereas those going downward will produce Compton electrons within a moderate distance. In both these cases, though their detailed behavior is probably different and their directions are opposite, the effective Compton-electron pulse is essentially vertical. Moreover, no matter where the burst occurs, there is inevitably some asymmetry in the emission and interaction of the photons. For example, the gamma-ray flux from an exploding weapon is itself never fully symmetric because of the presence of auxiliary apparatus, external structure, or the carrying vehicle. It should be noted that, while the "natural" asymmetries tend to be vertical, the other type may be oriented in any direction.

10.06 The Compton electrons created by the initial gamma radiation thus move away asymmetrically, at high velocity, from the exploding weapon. Since the remaining symmetrical components still compensate each other's effects, this motion appears from a distance to be a practically instantaneously accelerated pulse of current in one direction; it is, in other words, something like an "electric dipole" radiator of classical electrodynamics. The current pulse in the air radiates electromagnetic energy just as it would if it were flowing in a wire transmitting antenna, and this radiation constitutes the first part of the characteristic signal of the explosion.

10.07 When the Compton electrons move away from the explosion they leave behind the much slower moving positive ions, which are the other component of the ion pairs (§ 8.16). This relative displacement of positive and negative charges produces a radial electric field. In addition, in its passage through the air each Compton electron itself produces a large number of electron-ion pairs, perhaps 30,000, mostly toward the end of its path of 10 to 15 feet. Under the influence of the radial electric field, the large number of electrons now present will be driven back toward the burst point. This initiates a second pulse of current, but it is rapidly terminated by recombination of electrons with ions and by attachment of the electrons to neutral atoms and molecules in the air, even before the electric field is neutralized. The negative ions produced in the attachment process, and a corresponding number of positive ions, remain free a while longer because the ions, being heavier and less mobile than electrons, collide less frequently. This large volume of ionized gas (or "plasma") undergoes oscillations at characteristic frequencies similar to those observed in experimental plasmas in the laboratory. The oscillations damp out in a short time, as the negative particles (ions and electrons) combine with positive ions, but while they last they produce electromagnetic waves in the radiofrequency range.

CHARACTERISTICS OF THE COMPTON-ELECTRON SIGNAL

10.08 The effective rise-time of the main part of the initial signal pulse (produced by the Compton electrons) from surface or near-surface bursts is of the order of 10^{-8} second, so that oscillation frequencies as high as 100 megacycles (10^8 cycles) per second may be expected. However, only a very small part of the total electromagnetic energy radiated is carried at such high frequencies. In addition, the higher frequencies are attenuated much more rapidly than the lower ones in normal propagation through the atmosphere. The frequencies of the plasma oscillations, which continue for several milliseconds and radiate considerably more energy, are much lower. These frequencies are attenuated hardly at all in normal propagation. At the lower end of the spectrum are the extremely low frequencies (in the very low kilocycle region) which might be detected very close to any such excited radiating dipole; they would exist principally in the "induction" and "quasi-static" fields and not be radiated at all.

10.09 The electromagnetic signal, as detected at a range of a hundred miles or so, thus consists of a continuous spectrum with most of its energy distributed about a median frequency (10 to 15 kilocycles per second) which is related inversely to the yield. At much longer distances, of many hundreds or thousands of miles, the form and spectrum of the pulse are determined largely by the characteristics of the medium of propagation, i.e., the "duct" between the surface of the earth and the D- or E-region of the ionosphere (see § 10.16).

10.10 A somewhat similar explosively-excited vertical dipole radiator which is frequently encountered in nature is lightning, and the electromagnetic signal (or static) associated with lightning also has a peak in the region of 10 kilocycles. This must not be taken, however, to mean that there is a detailed similarity in the modes of generation of the electromagnetic signals from lightning discharges and from nuclear explosions. The transmission path largely obliterates the characteristics of the original signal in both cases.

THE FIELD-DISPLACEMENT MECHANISM

10.11 The second possibility which has been mentioned for the generation of radiofrequency signals by a nuclear explosion is considered to be of particular significance for extremely-high-altitude bursts. Immediately after the detonation has occurred, the hot weapon debris is essentially a highly ionized vapor (or plasma) which is expanding rapidly. A property possessed by all plasmas is a tendency to exclude a magnetic field, such as that of the earth, from its interior. The expanding plasma of weapon residues thus causes a violent distortion of the earth's magnetic field. As a result of the interaction between the geomagnetic field and the charged particles in the expanding plasma and in the very tenuous, largely ionized, surrounding gases, this disturbance propagates away from the burst region as a "hydromagnetic wave".

10.12 The hydromagnetic wave retains its identity and characteristics in propagating over very long distances at high altitudes, but at lower levels, where it interacts with the denser atmosphere, it is detected as an ordinary electromagnetic wave or magnetic disturbance. The field-displacement mechanism is believed to be especially important at very high altitudes where the air density is low and the expansion of the debris is not impeded by the atmospheric pressure. It is probable that the same mechanism may operate to produce an electromagnetic signal from an underground burst. The expansion of the debris is here limited to a few yards and the signal is therefore small, but it may be detectable at short ranges.

ATMOSPHERIC IONIZATION PHENOMENA

EFFECTS OF IONIZATION ON RADIO SIGNALS

10.13 Ionization, that is, the formation of ion pairs consisting of separated electrons and positive ions (§ 8.16), can be produced, either directly or indirectly, by the gamma rays and neutrons of the initial nuclear radiation, by the beta particles and gamma rays of the residual nuclear radiation, and also by the X-rays and even the ultraviolet light present in the primary thermal radiation (§ 2.38). Hence, after a nuclear explosion, the density of electrons in the atmosphere in the vicinity is greatly increased. These electrons can affect electromagnetic (radio and radar) signals in at least two ways. First, under suitable conditions, they can remove energy from the wave and thus attenuate the signal; second, a wave front traveling from one region into another in which the electron density is different will be refracted, i.e., its direction of propagation will be changed. It is evident, therefore, that the ionized regions of the atmosphere created by a nuclear explosion can influence the behavior of communications or radar signals whose transmission paths encounter these regions.

10.14 When a free electron is exposed to a radiofrequency wave, some of the energy of the wave is transferred to the electron as energy of vibration. If the electron does not lose this energy as the result of a collision with a neutral particle (atom or molecule) in the air, it will

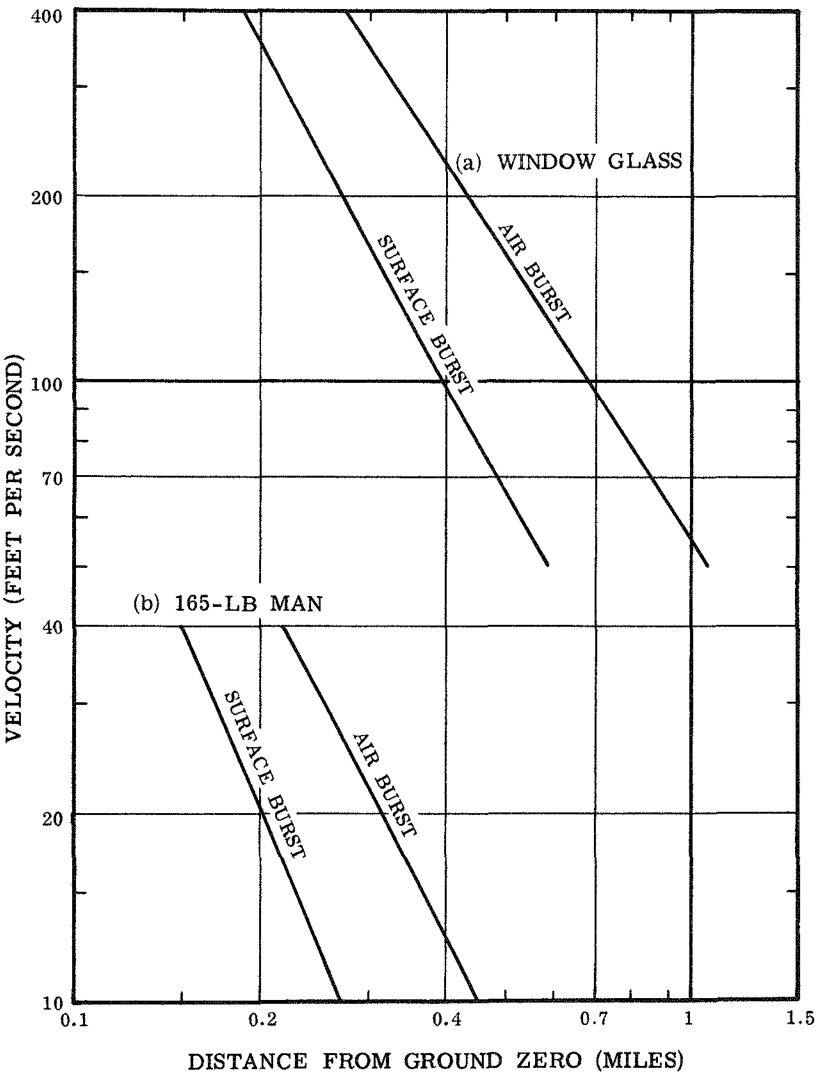

Figure 11.42. Velocities attained after 10 feet displacement by (*a*) 0.1- to 10-gram pieces of window glass, and (*b*) a 165-pound man in 1-kiloton surface and optimized air bursts.

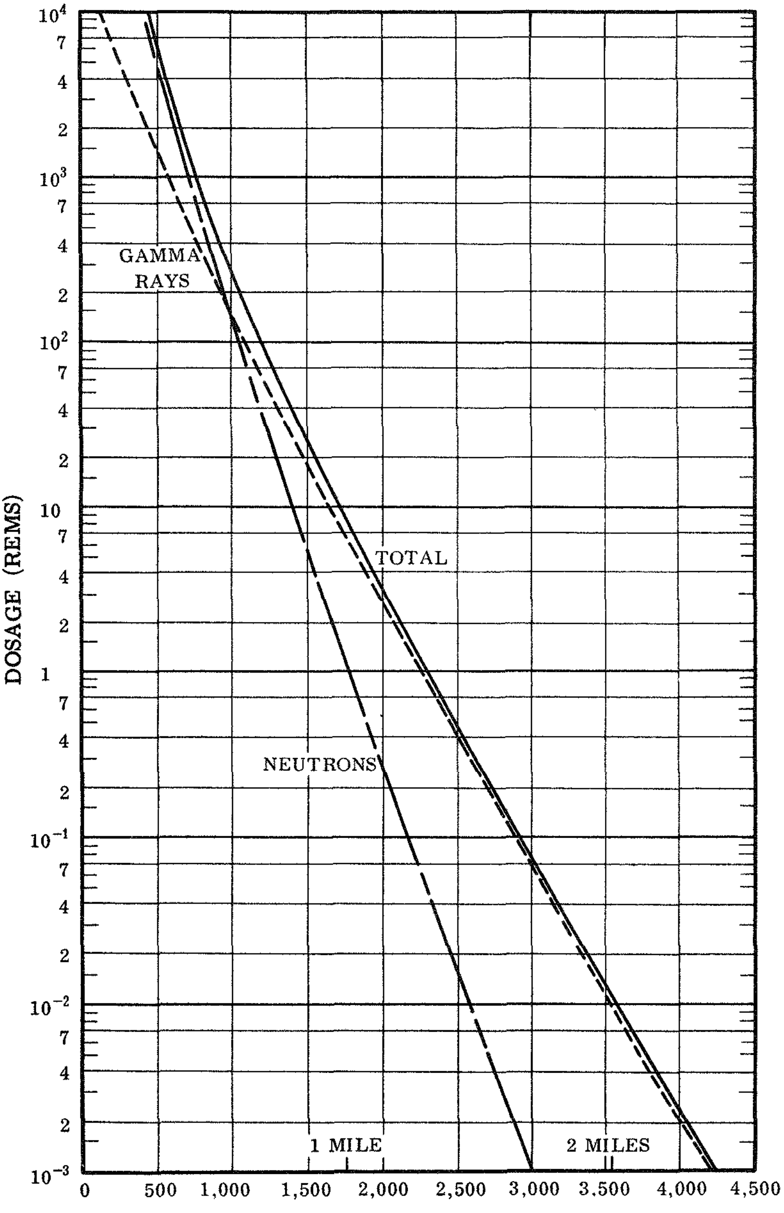

Figure 11.91. Initial gamma-ray and neutron doses as a function of range for a 1-kiloton air burst.

TABLE 11.111
SUMMARY OF CLINICAL EFFECTS OF ACUTE IONIZING RADIATION DOSES

Range	0 to 100 rems Subclinical range	100 to 1,000 rems Therapeutic range			Over 1,000 rems Lethal range	
		100 to 200 rems	200 to 600 rems	600 to 1,000 rems	1,000 to 5,000 rems	Over 5,000 rems
		Clinical surveillance	Therapy effective	Therapy promising	Therapy palliative	
Incidence of vomiting	None	100 rems: 5% 200 rems: 50%	300 rems: 100%	100%	100%	
Delay time	—	3 hours	2 hours	1 hour	30 minutes	
Leading organ	None	Hematopoietic tissue			Gastrointestinal tract	Central nervous system
Characteristic signs	None	Moderate leukopenia	Severe leukopenia; purpura; hemorrhage; infection. Epilation above 300 rems.		Diarrhea; fever; disturbance of electrolyte balance.	Convulsions; tremor; ataxia; lethargy.
Critical period post-exposure.	—	—	4 to 6 weeks		5 to 14 days	1 to 48 hours
Therapy	Reassurance	Reassurance; hematologic surveillance.	Blood transfusion; antibiotics.	Consider bone marrow transplantation.	Maintenance of electrolyte balance.	Sedatives
Prognosis	Excellent	Excellent	Good	Guarded	Hopeless	
Convalescent period	None	Several weeks	1 to 12 months	Long	—	
Incidence of death	None	None	0 to 80% (variable)	80 to 100% (variable)	90 to 100%	
Death occurs within	—	—	2 months		2 weeks	2 days
Cause of death	—	—	Hemorrhage; infection		Circulatory collapse	Respiratory failure; brain edema.

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*These publications may be obtained for a small charge from the Office of Technical Services, U.S. Department of Commerce, Washington 25, D.C.

CHAPTER XII

PRINCIPLES OF PROTECTION

BASIS FOR PROTECTIVE ACTION

INTRODUCTION

12.01 In the preceding chapters the phenomena and the destructive effects of nuclear explosions have been described in terms that are reasonably exact. In addition, the best available assessment of these effects on man have been presented. But in planning protection from the consequences of a nuclear explosion, so many uncertainties are encountered that precise analysis of a particular situation is impractical. For example, it is impossible to know in advance where or when a weapon will be detonated and what will be the explosive energy or the kind of burst. Nevertheless, there are some basic principles which, if properly understood and applied, could provide a measure of protection to a large proportion of the population in the event of a nuclear attack.

12.02 The most fruitful application of the principles of protection requires considerable preplanning on the part of individuals; however, some protection may be possible even in certain emergency situations if the principles are understood beforehand. It is the purpose of this chapter to present the quantitative aspects of weapons effects in a simplified form and to use them to explain the principles of protection. The information provided should be helpful in indicating the nature of the protection required and what steps must be taken in advance to achieve such protection. However, details of specific measures are not included since they are described in other publications.[1]

12.03 In the following sections the various effects of a nuclear explosion will be reviewed, with special reference to their ranges, and the principles of protection against each of these effects will be examined. At the same time, it will be shown how the measures used to provide protection from one particular effect can furnish protection against

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[1] See the bibliography at the end of the chapter.

others, so that the problem is less complicated than it might at first appear. Finally, a brief discussion will be presented of the planning needed to implement the principles of protection so as to make them effective.

IMMEDIATE AND DELAYED EFFECTS

12.04 The effects of a nuclear explosion may be divided into two broad categories, namely, immediate and delayed. The immediate effects are those which occur within a few minutes of the actual explosion. These include air blast and ground shock, thermal radiation (light and heat), and initial nuclear radiation.

12.05 The delayed effects are associated with the radioactivity present in fallout and neutron-induced radioactivity. The early fallout from a surface burst will begin to reach the ground within a few minutes after the explosion at close-in locations, and at increasingly later times at greater distances from ground zero, depending on the effective wind speed and direction. At distances of several hundred miles from the explosion, the fallout may not commence until as late as 24 hours after the burst time. Furthermore, several hours may elapse between the time of arrival of the fallout at any point and the time when deposition is essentially complete. A significant early fallout is associated with a surface burst or a subsurface burst which vents to the atmosphere, but not with an air burst or with a completely contained underground burst. Neutron-induced radioactivity, apart from that in the weapons residues, extends only a short distance from ground zero and it decays more rapidly than fallout.

12.06 Except for a contained burst, all presently known nuclear weapons produce delayed (world-wide) fallout. However, this part of the fallout is generally not apparent until several weeks or months have elapsed; it will not be treated here, since the present discussion refers to protection which is effective at the time of, and soon after, an explosion.

RANGES OF VARIOUS IMMEDIATE EFFECTS

12.07 When a nuclear weapon of known yield is detonated on the surface, at a particular height in the air, or at a particular depth below the surface, the ranges of the immediate effects are fairly well defined. For example, there will be an area surrounding ground zero within which the destruction due to blast and shock, and accompanying fires, will be so great that the survival of inhabitants in conventional structures is improbable. At considerably greater distances the immediate effects will be weaker and damage to structures will be minor, e.g., broken windows and damage to window frames and doors. The radiation from fallout may be significant in this region, but this is a delayed effect which will be considered later (§12.48 *et seq.*). Between the zone of total destruction and the area at which damage is not significant, there is a region in which protective measures can determine whether inhabitants survive, with little or no injury, or whether they become serious casualties.

12.08 The distances from ground zero within which various degrees of destruction may be expected depend primarily upon the energy yield of the explosion and the conditions of the burst, i.e., air, surface, etc. The topography and weather also influence these distances. By using the data presented in the earlier chapters, it is possible to draw a series of circles, as depicted in Fig. 12.08, representing areas within which effects of different types are to be expected for air bursts of various yields from 10 kilotons to 10 megatons TNT equivalent. The height of burst is such as to maximize the distance to which each effect extends; in other words, the radii of the circles give the greatest ranges at which the indicated thermal radiation, initial nuclear radiation, and overpressure levels will occur for any air burst of the given energy yield. It should be mentioned that the circular areas depict an idealized situation. Actually, as was the case in Japan, the pattern would be distorted by the conditions of the terrain, weather, etc. Two or more weapons detonated within a short distance can, of course, change the situation considerably.

12.09 Within the ring at which the blast overpressure is 5 pounds per square inch (5 psi), nearly all conventional houses will be damaged beyond repair. Even strong buildings, such as reinforced concrete and steel structures, will suffer damage and, without protective measures, the casualties to the inhabitants of this area will be high. In the central zone of heavy damage, there will alsa be a great fire hazard. Individuals in this area will be exposed not only to the effects of blast, but also to nuclear and thermal radiation. Apart from fortuitous circumstances, few persons will survive who have not sought protection in strong structures or shelters which will withstand the fire, blast, and shock and which will attenuate the radiation.

12.10 At distances from the burst where the blast overpreseure is 1 psi, the destructive effect of the air blast wave is minor. Window frames, doors, and plaster will suffer light damage. Window panes will be broken at much greater distances. The initial nuclear radiation dose will be so small that its immediate consequences are negligible, but thermal radiation may still be a significant source of

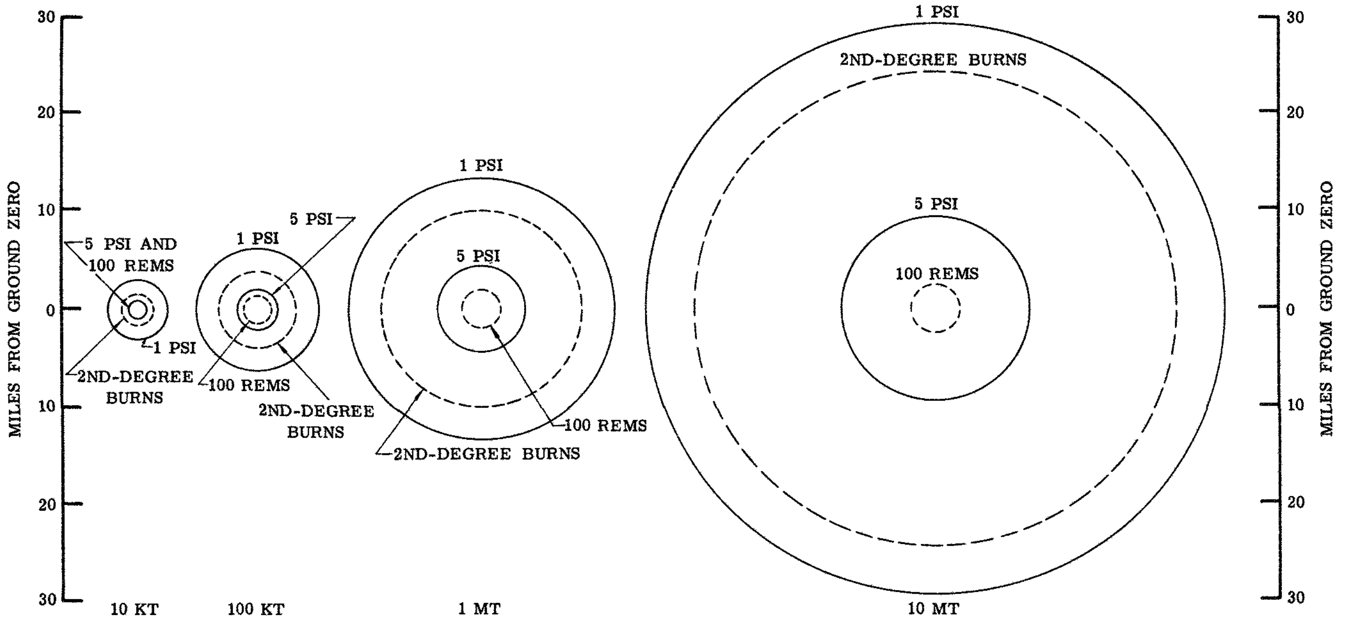

Figure 12.08. Idealized ranges for effects of air burst with the heights of burst optimized to give the maximum range for each individual effect.

casualties. Second-degree burns may be experienced at distances approaching those for 1 psi overpressure and less severe burns may be suffered at much greater distances from ground zero. Eye injury may also occur at even greater ranges and for high-altitude bursts of megaton weapons, this distance may be as much as several hundred miles. Furthermore, in dry, clear weather, many small fires would probably be ignited in newspapers and other thin combustible materials both within and outside of buildings.

EFFECTIVE PROTECTION AREAS

12.11 In Japan, where little evasive action was taken, the survival probability depended upon whether the individual was outdoors or inside a building and, in the latter case, upon the type of structure. At distances between 0.3 and 0.4 mile (530 and 700 yards) from ground zero in Hiroshima the average survival rate, for at least 20 days after the nuclear explosion, was less than 20 percent. Yet in two reinforced-concrete office buildings, at these distances, almost 90 percent of the nearly 800 occupants survived more than 20 days, although some died later from radiation injury. Furthermore, of approximately 3,000 school students who were in the open and unshielded within a mile of ground zero at Hiroshima, about 90 percent were dead or missing after the explosion. But of nearly 5,000 students in the same zone who were shielded in one way or another, only 26 percent were fatalities. These facts bring out clearly the greatly improved chances of survival from a nuclear explosion that could result from the adoption of suitable warning and protective measures.

12.12 As a rough guide, the inner range at which protection in conventional structures could be achieved may be supposed to be that where the overpressure is 5 pounds per square inch and the outer range, beyond which casualties will be small *for an air burst*, is at 1 pound per square inch (or the limit for second-degree burns). As seen above, survival in Hiroshima was possible in buildings at such distances that the overpressure in the open was 15 to 20 pounds per square inch. The somewhat arbitrary choice of an overpressure of 5 pounds per square inch, which was experienced at a little over a mile from ground zero in Japan, is thus very conservative. In any case, it is evident from the circles in Fig. 12.08 that the area over which protection could be effective in saving lives is roughly eight to ten times as great as that in which the chances of survival are small. It may be concluded, therefore, that a considerable proportion of the population "at risk" from a nuclear explosion would be in an area in which the casualty rate from the immediate effects may be significantly reduced provided protective measures are employed.

12.13 The various circles in Fig. 12.08 refer to an air burst, in which case there is essentially no early fallout. In the event of a burst at or near the surface, the situation would be different. The overpressure ranges would be reduced to roughly three-fourths and the second-degree burn range to about four-fifths of those shown in Fig. 12.08. However, there would be early fallout which might cover very extensive areas, from about 7 square miles for a 1-kiloton explosion to several thousand square miles for a 10-megaton yield (§9.100). Data that can be used for planning purposes are given in Chapter IX, but the conclusions concerning the extent of the hazard from early fallout cannot be expressed in simple diagrammatic form. However, it can be stated quite definitely that, following a surface burst of a high-yield weapon, a very large region extending possibly to three or four hundred miles downwind from the explosion center may become contaminated by the early radioactive fallout. The area affected will be influenced both by the total energy yield of the nuclear weapon and the proportion that is due to fission. The distance at which significant fallout will descend depends on the direction and speed of the wind at all levels from the radioactive cloud down to the ground.

12.14 From the standpoint of the present discussion, it cannot be too strongly emphasized that it is within this possibly large area of early fallout that preplanning of protective measures is of the utmost importance. At locations far from the point of attack, where the immediate effects of the nuclear explosion, i.e., blast, shock, initial nuclear radiation, and thermal radiation, are of absolutely no consequence, the delayed effect of fallout can be extremely serious unless steps are taken, in advance, to achieve protection when the emergency arises.

Relative Importance and Time Scale of Effects

12.15 It is not possible to arrange a single burst which maximizes the potential damage from each of the various immediate and delayed effects of a nuclear explosion. Thus, in a surface burst, the areas affected by blast, thermal radiation, and the initial nuclear radiation are appreciably less than for an air burst of similar energy yield. But, on the other hand, the surface burst is accompanied by early fallout whereas the air burst is not. Even with air bursts, the relative importance of the various effects depends on the height of burst.

12.16 In the following analysis an attempt is made to indicate the relative hazards associated with the various effects, as experienced by a ground observer, under different burst conditions for a given energy yield. The phenomena are given roughly in the order of their appearance. First, there is the flash of brilliant light accompanied and followed by heat, both of which are part of the thermal radiation. The initial nuclear radiation starts at the same time but may continue after the thermal radiation has ceased. Then ground and water shock, if any, will arrive, followed very soon by the air blast (and sound) wave; then will come the early fallout, if any, which may continue for several hours. The general conclusions are summarized in Table 12.16, the degree (or severity) of a particular effect being indicated by the number of asterisks. The various degrees are relative to each other for a given burst type, and are best interpreted in terms of the descriptions given below.

HIGH-ALTITUDE BURST

Light: Very intense.
Heat: Moderate, decreases with increasing burst altitude.
Initial nuclear radiation: Negligible.
Shock: Negligible.
Air blast: Small on the ground, decreasing with increasing burst altitude.
Early fallout: None.

Summary: The most significant effect will be flash blindness over a very large area; eye burns will occur in persons looking directly at the explosion. Other effects will be relatively unimportant.

AIR BURST

Light: Fairly intense, but much less than for high-altitude burst.
Heat: Intense out to considerable distances.
Initial nuclear radiation: Intense, but generally hazardous out to shorter distance than heat.
Shock: Negligible except for very low air bursts.
Air blast: Considerable out to distances similar to heat effects.
Early fallout: Negligible.

Summary: Blast will cause considerable structural damage; burns to exposed skin are possible over a large area and eye effects over a still larger area; initial nuclear radiation will be a hazard at closer distances; but the early fallout hazard will be negligible.

GROUND SURFACE BURST

Light: Less than for an air burst, but still appreciable.
Heat: Less than for an air burst, but significant.
Initial nuclear radiation: Less than for an air burst.

Shock: Will cause damage within about three crater radii, but little beyond.

Air blast: Greater than for an air burst at close-in distances, but considerably less at farther distances.

Early fallout. May be considerable (for a high-yield weapon) and extend over a large area.

Summary: Except in the region close to ground zero, where destruction would be virtually complete, the effects of blast, thermal radiation, and initial nuclear radiation will be less extensive than for an air burst; however, early fallout may be a very serious hazard over a large area which is unaffected by blast, etc.

SHALLOW UNDERGROUND BURST

Light, heat, and initial nuclear radiation: Less than for a ground surface burst, depending on the extent to which the fireball breaks through the surface.

Shock: Ground shock will cause damage within about three crater radii, but little beyond.

Air blast: Less than for surface burst, depending upon depth of burst.

Early fallout: May be considerable, if the depth of burst is not too large, and in addition there may be a highly radioactive base surge.

Summary: Light, heat, and initial nuclear radiation will be less than for a ground surface burst; early fallout can be significant, and at distances not too far from the explosion the base surge will be an important hazard.

WATER SURFACE BURST

Light: Somewhat more intense than for a ground surface burst.

Heat: Similar to ground surface burst.

Initial nuclear radiation: Similar to ground surface burst.

Shock: Water shock can cause damage to ships and underwater structures to a considerable distance.

Air blast: Similar to ground surface burst.

Early fallout: May be considerable.

Summary: The general effects of a water surface burst are similar to those for a ground surface burst, except that the effect of the shock wave in water will extend farther than ground shock. In addition, water waves can cause damage on a nearby shore by the force of the waves and by inundation.

SHALLOW UNDERWATER BURST

Light, heat, and initial nuclear radiation: Less than for a water surface burst, depending upon how much of the fireball breaks through the surface.

Shock: Water shock will extend farther than for a water surface burst.

Air blast: Less than for a surface burst, depending on the depth of burst.

Early fallout: May be considerable, if the depth of burst is not too large, and in addition there may be a highly radioactive base surge.

Summary: Light, heat, initial nuclear radiation, and blast effects will be less than for a surface burst; early fallout can be significant, but at distances not too far from the explosion the radioactive base surge will be an important hazard. Water waves can also cause damage, as in the case of a water surface burst.

CONFINED SUBSURFACE BURSTS

Light, heat, and initial nuclear radiation: Negligible or none.

Shock: Severe, especially at fairly close distances from the burst point.

Air blast: Negligible or none.

Early fallout: None.

Summary: If the burst does not penetrate the surface, either of the ground or water, the only hazard will be from ground or water shock. No other effects will be significant.

TABLE 12.16

RELATIVE DEGREES OF WEAPON EFFECTS FOR VARIOUS BURST CONDITIONS†

Burst conditions	Thermal radiation		Initial nuclear radiation	Ground or water shock	Air blast	Early fallout
	Light	Heat				
High altitude	****	**	*		*	
Air	***	****	****	*	****	
Ground surface	**	***	***	**	***	****
Water surface	***	***	***	**	***	****
Confined subsurface				****		

†The number of asterisks provides a rough indication of the relative importance of the indicated effect to a ground observer. Four asterisks imply that the effect is the most extensive for the given burst type; a blank space means that the effect is negligible or absent. For a more complete interpretation, see the accompanying text.

12.17 The time sequence referred to in § 12.16 brings up another aspect of nuclear weapons effects that has a bearing on protection. Except very close to ground zero, even the immediate effects do not occur simultaneously. The first, almost instantaneous, indication of a nuclear explosion in the air or on the earth's surface is a brilliant flash of light. In many circumstances, it may be feasible, after observing the flash, to take some appropriate protective action that could greatly minimize the degree of injury suffered. At distances beyond those at which the immediate blast, thermal, and initial nuclear effects of the explosion are significant, there may be some time to make final preparations to decrease the early fallout.

12.18 As a general guide for planning purposes, it is useful to know the magnitudes of the respective immediate effects at a range of distances from an explosion of given yield. This information can be obtained from various figures and tables given in earlier chapters and can be identified from the list in the table of contents at the beginning of the book. A tabular summary of part of the data for air bursts, which may be more convenient for some purposes, is given in Table 12.18. The heights of burst are such as to maximize the various effects. An asterisk indicates that the particular distance is within the fireball; otherwise a blank space implies that the value is too small to be significant. The initial nuclear radiation doses are not given for distances of 5 miles or more for they are extremely small even for a 10-megaton explosion.

BLAST EFFECTS

Effects on Structures

12.19 Injury to individuals both inside and outside a structure may occur because of the blast damage to that structure. Persons in the interior of the building can be injured and trapped by collapse and fire, and those outside can be hurt by flying debris. For these and other reasons, an important aspect of protection is an understanding of the relative ability of different structures to withstand damage from air blast. Both the peak overpressure and the peak dynamic (or wind) pressure determine the amount of the damage, but for certain structures one or the other of these pressures has the dominant effect. For most office-type and residential buildings, including ordinary houses, the extent of destruction is mainly dependent on the peak overpressure, and an approximate correlation between the overpressure and the expected physical damage is given in Table 12.19.

TABLE 12.18

WEAPON EFFECTS FOR AIR BURSTS WITH MAXIMIZED RANGES

Distances from ground zero	Explosion yield				
	1 KT	10 KT	100 KT	1 MT	10 MT
½ mile				(*)	(*)
Overpressure (psi)	4.1	13	46		
Thermal radiation (cal/cm^2)	3.8	38	380		
Initial nuclear radiation (rems)	670	6.7×10^3	7.6×10^4		
1 mile				(*)	(*)
Overpressure (psi)	1.5	4.5	14		
Thermal radiation (cal/cm^2)	0.9	9.1	91		
Initial nuclear radiation (rems)	9.1	91	1100		
2 miles					(*)
Overpressure (psi)	<1.0	1.7	5.0	16	
Thermal radiation (cal/cm^2)	0.2	2.1	21	210	
Initial nuclear radiation (rems)		0.2	1.9	35	
3 miles					
Overpressure (psi)		1.0	2.8	8.6	29
Thermal radiation (cal/cm^2)		0.9	9.0	90	900
Initial nuclear radiation (rems)				<1.0	2.6
5 miles					
Overpressure (psi)		<1.0	1.4	4.1	13
Thermal radiation (cal/cm^2)		<1.0	3.0	30	300
10 miles					
Overpressure (psi)			<1.0	1.5	4.5
Thermal radiation (cal/cm^2)			<1.0	6.6	66
20 miles					
Overpressure (psi)				<1.0	1.7
Thermal radiation (cal/cm^2)				1.4	14
50 miles					
Overpressure (psi)					<1.0
Thermal radiation (cal/cm^2)				<1.0	1.7

*Inside or close to fireball.

TABLE 12.19

RELATION BETWEEN PEAK OVERPRESSURE AND DAMAGE TO STRUCTURES

Structure type	*Damage*	*Overpressure (psi)*
Wood-frame building, residential type.	Moderate	2 to 3
	Severe	3 to 4
Wall-bearing, masonry building, apartment-house type.	Moderate	3 to 4
	Severe	5 to 6
Multistory, wall-bearing building, monumental type.	Moderate	6 to 7
	Severe	8 to 11
Reinforced-concrete (not earthquake-resistant) building, concrete walls, small window area.	Moderate	8 to 10
	Severe	11 to 15

12.20 This information can be utilized, in conjunction with the overpressure-distance data in Table 12.18, or with the curves in Chapter III, to determine approximately how far from ground zero the respective degrees of damage would be experienced for air bursts of various yields. The height of burst is assumed to be such as to maximize the area of structural damage. For example, it is seen from Table 12.18 that for a 1-megaton air burst a peak overpressure of 3 to 4 pounds per square inch is attained at about 5 miles from ground zero. This is consequently the approximate limit of moderate damage to brick, apartment-house type buildings and of severe damage to wood-frame dwellings.

12.21 The results of a more detailed analysis, based on the nomograph in Fig. 4.58a, are given in Table 12.21. The maximum distances from ground zero for moderate and severe damage to the four types of structures referred to above are recorded for air bursts (at optimum heights) of weapons with yields from 1 kiloton to 10 megatons. For a surface burst, the damage range is three-quarters that for an air burst of the same yield.

TABLE 12.21

MAXIMUM RANGES FROM GROUND ZERO FOR STRUCTURAL DAMAGE FROM AIR BURSTS*

		Explosion yield				
		1 KT	*10 KT*	*100 KT*	*1 MT*	*10 MT*
Structure type	*Damage*	*(Distance in miles)*				
Wood-frame building, residential type.	Moderate	0. 66	1. 5	3. 2	6. 6	14
	Severe	0. 47	1. 1	2. 4	5. 5	12
Wall-bearing, masonry building, apartment-house type.	Moderate	0. 53	1. 1	2. 4	4. 7	10
	Severe	0. 34	0. 76	1. 7	3. 5	8. 7
Multistory, wall-bearing building, monumental type.	Moderate	0. 36	0. 76	1. 6	3. 5	7. 4
	Severe	0. 23	0. 55	1. 3	2. 8	6. 1
Reinforced-concrete (not earthquake-resistant) building, concrete walls, small window area.	Moderate	0. 28	0. 61	1. 5	3. 4	7. 2
	Severe	0. 19	0. 44	1. 1	2. 5	5. 9

*For a surface burst the respective distances are three-quarters of those for an air burst of the same yield.

12.22 Information on the effects of 20-kiloton and 1-megaton air bursts on a variety of structures, including many which are damaged by dynamic loading, is given in Tables 12.22 a and b. These refer to "typical" air bursts at heights of 1,850 and 6,800 feet, respectively,

TABLE 12.22a

DAMAGE RANGES FOR 20-KT TYPICAL AIR BURST

Peak Wind Velocity (mph)	Positive Phase Duration (sec)	Peak Dynamic Pressure (psi)	Peak Over-Pressure (psi)	Range from Ground Zero MILES	Range from Ground Zero 1000 FT	
				2		Light damage to window frames and doors, moderate plaster damage out to about 4 miles; glass breakage possible out to 8 miles.
70	0.95	0.09	2.0		10	
				1.8		Fine kindling fuels: ignited.
79	0.94	0.12	2.3		9	Wood-frame buildings: moderate damage. Smoke stacks: slight damage.
				1.6		
93	0.92	0.17	2.7		8	
				1.4		
112	0.90	0.27	3.2		7	Wood-frame buildings: severe damage. Radio and TV transmitting towers: moderate damage. Wall-bearing, brick building (apartment house type): moderate damage.
				1.2		
139	0.86	0.42	4.2		6	
						Wall-bearing, brick buildings (apartment house type): severe damage.
				1.0		Telephone & power lines: limit of significant damage.
190	0.80	0.80	6.0		5	Multistory, wall-bearing buildings (monumental type): moderate damage. Light steel-frame, industrial buildings: moderate damage.
				0.8		
291	0.72	1.50	10.0		4	
						Multistory, wall-bearing buildings (monumental type): severe damage. Light steel-frame industrial buildings: severe damage. Highway and RR truss bridges: moderate damage.
				0.6		
431	0.63	3.90	16.3		3	
						Multistory, steel-frame building (office type): severe damage. Transportation vehicles: moderate damage. Multistory, blast-resistant designed, reinforced-concrete building: moderate damage.
				0.4		
459	0.54	7.50	22.5		2	Multistory, reinforced-concrete, frame building (office type): severe damage. Multistory, blast-resistant designed, reinforced-concrete buildings: severe damage. All other (above ground) structures: severely damaged or destroyed.
260	0.44	2.70	30.0	0.2	1	
				0	0	Ground zero for 20 KT air burst.

TABLE 12.22b

DAMAGE RANGES FOR 1-MT TYPICAL AIR BURST

Peak Wind Velocity (mph)	Positive Phase Duration (sec)	Peak Dynamic Pressure (psi)	Peak Over-Pressure (psi)	Range from Ground Zero MILES	Range from Ground Zero 1000 FT	
				10		Light damage to window frames and doors, moderate plaster damage out to about 15 miles; glass breakage possible out to 30 miles.
44	3.45	0.036	1.2		50	
				9		
51	3.45	0.049	1.4		45	Fine kindling fuels: ignited.
				8		
60	3.44	0.072	1.7		40	
				7		
72	3.43	0.11	2.1		35	Smokestacks: slight damage.
				6		
89	3.40	0.16	2.6		30	Wood-frame buildings: moderate damage. Radio and TV transmitting towers: moderate damage.
				5		Wood-frame buildings: severe damage. Telephone & power lines: limit of significant damage.
117	3.24	0.28	3.5		25	
						Wall-bearing, brick buildings (apartment house type): moderate damage.
				4		Wall-bearing, brick buildings (apartment house type): severe damage.
177	3.02	0.60	5.5		20	Light steel-frame, industrial buildings: moderate damage. Light steel-frame, industrial buildings: severe damage. Multistory, wall-bearing buildings (monumental type): moderate damage.
				3		
278	2.69	1.40	9.4		15	Multistory, wall-bearing buildings (monumental type): severe damage. Highway and RR truss bridges: moderate damage. Multistory, steel-frame building (office type): severe damage. Transportation vehicles: moderate damage.
				2		
464	2.25	5.22	18.0		10	Multistory, reinforced-concrete frame buildings (office type): severe damage.
307	1.75	3.60	27.0	1	5	Multistory, blast-resistant designed, reinforced-concrete buildings: moderate. Multistory, blast-resistant designed, reinforced-concrete buildings: severe. All other (above ground) structures: severely damaged or destroyed.
				0	0	Ground zero for 1 MT air burst.

whereas the results in Table 12.21 and in Figs. 4.58 a and b are for heights of burst which produce a maximum area of damage for each type of structure.

EFFECTS ON PERSONNEL

12.23 For ease of understanding, the effects of air blast on personnel are referred to as either direct or indirect. Among the direct effects are those due to overpressure, such as damage to the ear drums and the lungs (§§ 11.29, 11.31). These occur at close-in distances. An indirect type of injury can arise from displacement of the body as a whole by dynamic (or wind) pressure and its resulting impact with a hard surface (§ 11.33 *et seq.*). This can be experienced at distances where the overpressure (and dynamic pressure) are relatively low, because the maximum wind velocities in the open can still be quite high (Tables 12.22 a and b). Indirect blast injuries can also arise from broken glass and flying debris of various kinds produced by the destruction of buildings. These injuries could be quite numerous over the area in which the overpressure is about 2 pounds per square inch or more.

PROTECTIVE CONSTRUCTION AND EVASIVE ACTION

12.24 It is impractical to construct an aboveground conventional building, e.g., office, apartment, or warehouse, that will resist overpressures greater than 25 psi or more, but by taking certain precautions the blast resistance of any structure can be increased somewhat without adding seriously to its cost. The building should be designed for a prescribed overpressure of a certain duration in order that the structure may have essentially uniform strength in different parts. In this connection, it should be borne in mind that the reflected pressure on a wall facing the blast wave will be more than twice as great as on a side wall (§ 3.71). Sturdy connections between beams and columns, such as are commonly used in earthquake-resistant design, and the extensive use of bracing will generally increase the strength of the structure.

12.25 For large buildings, walls of reinforced concrete, which also contain the frame, will give a structure having maximum blast resistance. Such buildings withstood the blast from a nuclear bomb in Japan (Chapter V), although the interiors were badly damaged by fire. Unreinforced block construction, with brick, concrete, or glass, is not only much less able to withstand blast than is a reinforced-concrete structure, but produces more flying debris when it is damaged.

12.26 In industrial-type structures, e.g., for housing machine tools, which have walls made of a frangible material, such as asbestos sheet, rather than of metal, the blast wave will destroy the siding with the result that the loading on the frame will be reduced mainly to that from wind drag. The lightweight debris produced will cause little damage to the machines inside the building. However, shelters are necessary to protect personnel in such buildings from flying pieces of frangible material.

12.27 Blast resistant personnel shelters have been tested at nuclear weapon tests at overpressure levels up to 200 pounds per square inch. Animals exposed at overpressures up to 90 pounds per square inch in such shelters have survived. Similar or more modest shelters can be constructed at relatively low cost if they are planned and built concurrently with new construction. Essential features of blast-resistant shelters are structural strength to resist blast loads to the selected overpressure level, an access door of corresponding strength, a protected ventilation system to permit occupancy of the shelter until fires have subsided, and adequate nuclear radiation shielding.

12.28 Where a blast-resistant shelter is not available, protection should be sought in the strongest building that is accessible. Protection against flying debris can be obtained by taking refuge in a location, preferably selected in advance, that is least likely to be entered by blast debris. In addition, individuals should stay away from windows and easily breakable materials, such as plaster walls or ceilings. In the collapse of buildings as a result of blast, heavy members and pieces of structural materials and contents will fall or be hurled about. There is a dual hazard of being hit and trapped; therefore, positions next to walls in basements offer the best protection. Above ground, however, the safest locations are generally near, but not against, walls and away from doors and windows.

12.29 Even if there is no prior warning of a nuclear attack and the first indication is the flash of light, there may still be the opportunity to take some protective action against the effects of blast. In Table 12.29 are given some approximate values of the times which elapse between the instant of the explosion and the arrival of the blast wave front at various distances from ground zero for air bursts of energy yields from 1 kiloton to 10 megatons TNT equivalent. For distances at which the peak overpressure is small, e.g., 1 pound per square inch or less, the times are not included.

TABLE 12.29—ARRIVAL TIME FOR PEAK OVERPRESSURE

Distance (miles)	*Explosion yield*				
	1 KT	*10 KT*	*100 KT*	*1 MT*	*10 MT*
			(Time in seconds)		
1	4.3	3.6	3.7	2.5	1.5
2	>9	8.1	7.4	6.5	5.0
3	--------	>13	12	11	9.5
5	--------	--------	21	20	16
7	--------	--------	>30	28	26
10	--------	--------	--------	42	37
20	--------	--------	--------	>90	83
30	--------	--------	--------	--------	>130

12.30 It is seen that at 10 miles from a 10-megaton air burst, which is within the area where protection against blast could be effective, some 37 seconds would elapse before arrival of the blast wave. If prompt action is taken, a person in a building could reach a position of the type indicated above. In the open, some protection against the blast may be obtained by falling prone, and remaining in that position until the wave has passed. In the prone position, with the head directly toward or directly away from the explosion, the area of the body exposed to the onrushing blast wave is relatively small and the danger of displacement is thereby decreased (cf. § 11.38).

THERMAL RADIATION EFFECTS

EFFECTS ON PERSONNEL

12.31 The main direct effects of thermal radiation on human beings are skin burns, generally called flash burns to distinguish them from flame burns, and permanent or temporary eye damage. Burns are classified by "degree"; first-degree burns being mild in nature, roughly similar to moderate sunburn; they should heal without special treatment. Second-degree burns are associated with blister formation and if a significant area of the body is involved, medical attention is necessary (§ 11.44 *et seq.*). The approximate limiting distances from air bursts of various total yields at which first- and second-degree burns of exposed (light-colored) skin may be expected are given in Table 12.31. Third-degree burns, which involve the entire thickness of the skin, can occur at shorter ranges. For a surface burst, the respective distances are decreased to about four-fifths of the values in the table. The ranges shown are actually from the burst point rather than from ground zero, but at the heights of burst that maximize the distances over which burns are experienced, the differences are small.

TABLE 12.31

RANGES FROM GROUND ZERO FOR BURNS TO BARE SKIN FROM AIR BURSTS*

	Explosion yield				
	1 KT	*10 KT*	*100 KT*	*1 MT*	*10 MT*
	(Distance in miles)				
First-degree burn	0. 7	1. 9	5. 3	14	>30
Second-degree burn	0. 5	1. 5	4. 0	11	24

*For a surface burst the distances are about four-fifths those for an air burst of the same yield.

12.32 The data presented in Table 12.31 are applicable to reasonably clear atmospheric conditions. Fog or mist near the ground or a layer of cloud between the point of the explosion and the ground would attenuate the thermal radiation and thus decrease the ranges at which flash burns may be experienced by exposed persons. However, snow on the ground or cloud layers above the explosion provide reflecting surfaces which increase these ranges.

12.33 Eye injuries are of two main types: temporary (flash blindness) and permanent (chorioretinal burns), as described in § 11.69 *et seq.* Both kinds of injury can occur at great distances from the explosion, considerably greater even than those for first-degree burns given in Table 12.31. The nature and extent of the eye injury depends on the yield and type of burst, on the orientation of the observer to the burst, on the clarity of the atmosphere, and on the size of the pupil opening. As a general rule, permanent eye injury would be expected only in those persons who were looking directly at the fireball. Flash blindness, on the other hand, could be quite general over a large area.

PROTECTIVE MEASURES

12.34 In an air or surface burst, the thermal radiation is received in two pulses, in each of which there is a maximum of intensity followed by a decrease. If an individual is caught in the open or is near a window in a building at the time of a nuclear explosion, evasive action to minimize flash burn injury should be taken, if possible, before the maximum in the second pulse. At this time only 20 percent of the thermal energy will have been received, so that a large proportion can be avoided if shelter is obtained before or soon after the second thermal maximum. The elapsed times between the instant of the explosion and the second thermal maximum for air and surface bursts of various energy yields are recorded in Table 12.34. From this table it is seen that the prospects of being able to take evasive action are not good for air or surface bursts of low energy yield, but some possibility may exist for explosions in the megaton range.

TABLE 12.34

TIME TO SECOND THERMAL MAXIMUM

	Explosion yield				
	1 KT	*10 KT*	*100 KT*	*1 MT*	*10 MT*
Time (seconds)	0. 03	0. 1	0. 3	1. 0	3. 2

12.35. The major part of the thermal radiation travels in straight lines, and so any opaque object interposed between the fireball and the exposed skin will give some protection. This is true even if the object is subsequently destroyed by the blast, since the main thermal radiation pulse is over before the arrival of the blast wave.

12.36 At the first indication of a nuclear explosion, by a sudden increase in the general illumination, a person inside a building should immediately fall prone, as described in § 12.30, and, if possible, crawl behind or beneath a table or desk or to a planned vantage point. Even if this action is not taken soon enough to reduce the thermal radiation exposure greatly, it will minimize the displacement effect of the blast wave and provide a partial shield against splintered glass and other flying debris. An individual caught in the open should fall prone to the ground in the same way, while making an effort to shade exposed parts of the body. Getting behind a tree, building, fence, ditch, bank, or any structure which prevents a direct line of sight between the person and the fireball, if possible, will give a major degree of protection. If no substantial object is at hand, the clothed parts of the body should be used to shield parts which are exposed. There will still be some hazard from scattered thermal radiation, especially from high-yield weapons at long range, but the decrease in the direct radiation will be substantial.

12.37 Clothing of the proper kind provides good protection against flash burns. Materials of light color are usually preferable to dark materials because the former reflect the radiation. Clothing of dark shades absorbs the thermal radiation and may become hot enough to ignite, so that severe flame burns, which are more serious that the flash burns, may result. Woolen materials give better protection than those of cotton of the same color, and the heavier the fabric the greater the protection. An air space between two layers of clothing is very effective in reducing the danger of flash burns.

12.38 Protection against eye injury is difficult, especially for those persons who happen to be facing the burst point. The blink reflex, i.e., the automatic blinking of the eye, which requires 0.15 second, may be helpful in providing some protection from air and surface bursts in the megaton range. It is doubtful, however, if much can be done at those distances where the same total amount of thermal energy is received from weapons of lower energy. In a nuclear explosion at high altitude, that is, at heights above 20 miles, the thermal radiation is emitted in a single rapid pulse. Assuming the total thermal energy received by a person at a particular location is sufficient to cause flash burns or eye injury, it seems improbable that any evasive action will be effective, as even the involuntary blink will not be in time to help very much. Ordinary sunglasses will provide little or no protection against eye damage, since much more opaque material would be required to decrease the radiation intensity. In all cases individuals should make every effort to avoid looking toward the fireball.

FIRE PROTECTION

12.39 After a nuclear attack on an urban area, extensive fires may develop as they did in Japan. Such fires were started both directly by thermal radiation and by secondary blast effects, i.e., overturning of stoves, short circuiting of electrical wires, etc. (§ 7.69). Appropriate fire control action may be directed along three lines, namely, (1) reduction of potential ignition points, (2) provision for isolation or rapid extinction of ignitions to prevent formation of large fires, and (3) minimization of the consequences should large-scale fires develop.

12.40 Since the elimination of wood as a construction material for houses is virtually impossible, potential ignition points can be decreased by continuous upkeep of existing wood structures and by taking steps to keep yards free from all combustible trash. As stated in § 7.57 *et seq.*, it was clearly demonstrated at the 1953 tests in Nevada that a well-maintained house, with a yard free from trash, is much more capable of withstanding the thermal effects of a nuclear explosion than is a poorly-maintained house or one with an unkept yard. Fire-resistive furnishings, e.g., draperies, rugs, etc., made of vinyl plastic or wool, also proved to be advantageous in these tests.

12.41 The second aspect of fire control action is to plan and train for the elimination of small fires before they can grow into serious ones.

In Japan the fires were so numerous and spread so rapidly that it would have been beyond the capability of regular fire departments to deal with them even if the latter had survived the bombings. The training of private individuals in emergency methods of firefighting, such as were developed in Europe during World War II, is therefore desirable. By extinguishing small fires soon enough, the number of serious fires may be sufficiently small to be dealt with by professional firefighters.

12.42 Conventional methods for preventing the spread of large fires, by the use of natural and artificial fire breaks, were not too successful in Japan, for the reasons mentioned in § 7.72. Nevertheless, consideration should be given to the provision of adequate fire breaks and to the zoning and planning of urban areas. As seen in § 7.55, the potential for the development and spread of fires is greatest in wholesale distribution and slum residential areas. Dispersal and protection of utilities and emergency services should be included in such planning.

INITIAL NUCLEAR RADIATION

Effects on Personnel

12.43 The initial nuclear radiation consists of gamma rays and neutrons received during the first minute after the explosion. Doses of this radiation up to 100 rems, over the whole body, would have little or no immediate observable effects on exposed individuals. The only effect expected might be a slight feeling of fatigue in some people. Many persons receiving larger doses, up to 200 rems, would not be greatly affected by the radiation, except for blood changes. For the present purpose, however, it will be supposed that a whole-body dose of 100 rems will cause few, if any, casualties requiring medical attention. At the other extreme, it is probable that every person receiving 1,000 rems over the whole body will become sick within 4 hours (or less) of exposure and will die in 2 or 3 weeks. Between these extremes there is a great deal of variation in the expected effects on personnel, but at an exposure of around 400 to 500 rems, all will be nauseated and vomit on the first day, and most will require medical care. However at this exposure, at least one-half of the people will probably recover.

12.44 The actual distances from air bursts of various yields at which the initial nuclear radiation will produce doses of 100, 500, and 1,000 rems, respectively, to completely unprotected individuals are shown in Table 12.44. However, the heights of burst which maximize these distances are such that the latter are not very different from the ground zero ranges. For purposes of comparison, the distances for an overpressure of 5 pounds per square inch and for second-degree flash burns of exposed skin are included. It is seen that the hazards from blast and thermal radiation extend to much greater distances than do those from initial nuclear radiation, especially for weapons of yields in excess of 10 kilotons. For example, an individual 2 miles from a 1-megaton burst probably would show no significant symptoms of nuclear radiation sickness, but the thermal radiation exposure would be 210 calories per square centimeter (see Table 12.18). Less than 7 calories per square centimeter are sufficient to produce a second-degree skin burn from an explosion of 1 megaton. The corresponding blast wave overpressure of 18 pounds per square inch would cause severe damage to the strongest conventional structures (cf. Table 12.19).

TABLE 12.44

RANGES FROM GROUND ZERO FOR VARIOUS INITIAL NUCLEAR RADIATION DOSES FROM AIR BURSTS*

	Explosion yield				
	1 KT	*10 KT*	*100 KT*	*1 MT*	*10 MT*
	(Distances in miles)				
Radiation Dose					
100 rems	0. 7	1. 0	1. 3	1. 8	2. 4
500 rems	0. 6	0. 8	1. 1	1. 5	2. 1
1,000 rems	0. 5	0. 7	1. 0	1. 4	2. 0
Other Effects					
5 psi	0. 4	0. 9	2. 0	4. 3	9. 2
Second-degree burns	0. 5	1. 5	4. 0	11	22

*The distances for a specified radiation dose are slightly less for a surface burst.

PROTECTION FROM INITIAL NUCLEAR RADIATION

12.45 It is apparent that for weapons with yields greater than 10 kilotons, the regions in which large doses of initial nuclear radiation could be received are those of high blast pressure and intense thermal radiation. Protection against all three effects would be provided by a massive reinforced, fire-resistant building. An 18-inch thickness of concrete, for example, would reduce the fatal dose of 1,000 rems to the tolerable one of about 100 rems. Thus, aboveground buildings of massive construction would provide some protection against the initial nuclear radiation. Additional protection may be obtained in basements beneath substantial concrete floor slabs. The surrounding earth also helps in this connection; a 26-inch thickness of earth attenuates the radiation by a factor of about ten and 3 feet by about thirty.

12.46 The immediate evasive action suggested earlier for limiting the effects of thermal radiation and blast to a person in the open may assist, to a lesser extent, in reducing the dose of initial nuclear radiation. From high-yield weapons, in particular, a second or two elapses before much of the nuclear radiation is delivered at distances where survival is possible (§ 8.43). Table 12.46 gives the percentage of the total initial gamma-radiation dose received at given distances from 20-kiloton and 5-megaton explosions as a function of time. The total unshielded dose would be about 4,500 roentgens in each case.

TABLE 12.46

INITIAL GAMMA-RADIATION DOSE AS A FUNCTION OF TIME

Explosion yield	Distance (miles)	*Time (seconds)*						
		1	*2*	*4*	*7*	*10*	*15*	*20*
		Percentage of initial gamma-radiation dose delivered						
20 KT	0.5	67	78	88	95	97	100	-----
5 MT	1.5	5	17	43	76	90	98	100

12.47 As shown by the table, there is some possibility of reducing the radiation dose by immediate evasive action. However, from the numbers given above for the attenuation by concrete and earth, it is obvious that a nuclear radiation shield must be very massive if it is to be effective. Normal clothing, for example, will do little to attenuate initial nuclear radiation, although it may provide complete protection from thermal radiation. Another difficulty in connection with obtaining shelter in the open is the scattering of nuclear radiation, so that it may reach a person from many directions and not just along a direct line from the point of explosion.

RESIDUAL NUCLEAR RADIATION

FALLOUT HAZARD

12.48 The principal effects on personnel from residual radiation are similar to those from comparable doses of initial nuclear radiation as described in the preceding section. However, the hazards of exposure to residual radiation are entirely different from exposure to initial radiation and these hazards are described in this section.

12.49 Protection against residual nuclear radiation occupies a position of special significance. Because the early fallout can cover an area much larger than that over which blast, thermal radiation, and initial nuclear radiation are significant, it is possible for people to become casualties at such distances from the explosion that the immediate effects are negligible or completely absent. As noted earlier, it is not feasible to state the degree of hazard from residual radiation in a reasonably accurate manner because it is so highly dependent upon conditions, especially wind speeds and directions over a considerable height. It is certain, however, that a surface burst in the megaton range will lead to contamination of very large areas by early fallout. This fallout will reach the ground very soon after the explosion at near distances, but at distances of several hundred miles, up to 24 hours may elapse before the fallout starts to arrive.

12.50 The early fallout hazard is of two main kinds: one results from the actual contact of the radioactive material with the skin, causing what are called "beta burns" produced by the action of the beta particles, and the second is due to the continuous exposure of the body to gamma rays, both direct and scattered, from fallout particles. It is with the second of these hazards that the discussion here will be mainly concerned. The protective measures for use against beta burns are chiefly associated with keeping the dust-like particles off the skin. If the fallout dust does get on the skin, it should be immediately washed off with soap and water. The possible hazard from entry of radioactive material into the body by ingestion will be considered later (§ 12.66 *et seq.*).

INDUCED RADIOACTIVITY

12.51 In addition to the radioactive fallout, there may be a residual radiation hazard near ground zero caused by induced activity resulting from the capture of neutrons by various elements in the soil, especially sodium and manganese. The induced-activity hazard may exist on the ground after an air burst when the initial fallout is virtually absent. However, this activity not only decays much more rapidly than does that from fallout, but it extends only a short distance (1 mile or less) from ground zero. Since the destruction in this area would be considerable, the only persons entering it for some time after the explosion should be rescue teams and others performing urgent missions. Such teams would be equipped with instruments to inform them of the radiation hazard.

PROTECTIVE MEASURES

12.52 Assuming the population is to remain in the fallout area, and not be evacuated, it is necessary to obtain protection which attenuates the gamma radiation. The basic principle to be borne in mind is that any massive or thick material will decrease the nuclear radiation level to some extent, whereas lighter construction, e.g., window areas, hollow, thin, or light walls, etc., permits the radiation to penetrate. A layer of concrete 8 inches thick or of earth 12 inches thick will yield an attenuation factor of 10; [2] doubling these thicknesses will increase the factor to 100. Thus, each extra foot of earth between an individual and the fallout will increase the protection factor tenfold. It should be remembered that scattered radiation will come from many directions, and so protection is necessary from all directions, either by the use of a mass of material or by distance.

12.53 Information has been published that describes procedures and standards for evaluating the potential of existing structures as fallout shelters and for modifying such structures to improve their effectiveness in this respect. The recommended procedures and standards may also be utilized in the design of new structures. Furthermore, instructions for building simple and effective fallout shelters are readily available. Basically, a fallout shelter is a structure with massive walls and ceiling. Practical materials of construction are earth, concrete, or solid masonry. Attenuation of the gamma radiation is provided by absorption in these materials and by the distance separating the fallout particles from the people in the shelter.

12.54 Since a shelter may have to be occupied continuously for periods as long as 2 weeks, until the natural decay of the radioactivity outside will allow the people to emerge, stocks of food and other supplies will be required. Where fallout arrives soon after the explosion, the early radiation dose rate will be high. It may then be necessary to wait several days before it is possible to come out of the shelter for more than a limited period without risking a radiation dose of sufficient magnitude to cause serious illness. In the path of the fallout, the early radiation levels will be lower at more distant points from the explosion, and the time necessary to occupy the shelter will be shorter, unless "hot spots" are present (§ 9.55). However, in any area where contamination is at all significant, it will probably be necessary to spend the first day or two after the burst sheltered from the residual gamma radiation. It is during the period immediately following the nuclear explosion, when the radiation level is at its highest, that protection is most important.

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[2] It should be noted that more than twice these thicknesses of concrete (18 inches) and of earth (26 inches) are required to attenuate the initial nuclear radiation to the same extent (§ 12.45) because the energy of the initial gamma rays is greater than in the residual (fallout) radiation.

12.55 A fallout shelter of the kind referred to in § 12.53 will provide a protection factor of about 200 from the residual radioactivity; in other words, the dose rate in the shelter will be only ½ percent of that measured outside at a height of 3 feet above the ground. Where a shelter is not available, a similar protection factor from radiation can be obtained in the following manner in a small area of the basement of a two-story house. A sturdy table is placed in a corner adjacent to an unexposed outer wall and covered with 10 to 12 inches of soil, sandbags, solid concrete block, etc., according to what is available. If there are no heavy partitions or walls near the corner of the basement chosen, a layer of sandbags or concrete blocks should be stacked along the walls up to the height of the material on top of the table. Within the area under the table, there will be a protective factor of at least 100 from fallout radiation. The disadvantage of this type of protection is that it is unlikely that stocks of food and water would be available within the shelter, so that it could not be occupied continuously for an extended period, as could the more permanent type outlined previously. In almost any house with a buried basement, having uniformly thick exterior walls, a protection factor of 20 to 40 is possible. The maximum protection can be obtained near the floor and in the corners of the basement adjacent to an unexposed outer wall.

12.56 Before leaving a shelter, either temporarily or permanently, it is highly desirable that the radiation dose rate, both in the immediate area of the shelter and in the surrounding vicinity, be known. Marked variations in fallout patterns have been observed in weapons tests, with unexpected areas (hot spots) of exceptionally high activity. Hence, it is not sufficient to know merely that a nearby location is relatively safe. Communications equipment, e.g., battery-powered radios, and radiation measuring instruments should be in shelters. Otherwise it will not be possible to obtain information on radiation dose rates in the locality and in the immediate vicinity of the shelter, particularly at early times when high radiation levels will prevent radiation monitors from moving safely and freely about the community. As a rough rule-of-thumb, it may be stated that for every sevenfold increase in time, the radiation level will decrease by a factor of 10, provided the fallout is complete. For example, the radiation level at the end of 7 days will have fallen to roughly one-tenth of that at the end of 1 day. At the end of 49 days, it will have decreased by a factor of 100, etc.[3]

12.57 It is appropriate to mention here that whether or not fallout is visible to the eye, its measurement requires the use of suitable

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[3] The rule is applicable to any unit of time; thus at 7 hours the residual radiation level will be one-tenth of that at 1 hour, at 14 hours it will be one-tenth of that at 2 hours, and so on, provided the fallout is complete at both times.

instruments sensitive to nuclear radiations. Some, although perhaps not all, of the fallout in the Marshall Islands, after the test explosion of March 1, 1954 (§ 9.100 *et seq.*), could be seen as a white powder or dust. This was due, partly at least, to the light color of the calcium oxide or carbonate of which the particles were mainly composed. It is probable that whenever there is sufficient fallout to constitute a hazard, the dust will be visible. Nevertheless, continuous monitoring with instruments for radioactive contamination would appear to be essential in all areas in the vicinity of the burst.

RADIOLOGICAL SURVEYS

12.58 As soon after a nuclear explosion as conditions permit, radiological monitoring surveys will have to be initiated for the purpose of developing information on the extent and levels of the contamination. At early times in heavily contaminated areas, where dose rates will be very high, only the most limited amount of monitoring can be accomplished by individuals with hand-carried instruments. In these circumstances, some kind of remote radiation monitoring equipment may be necessary. This will permit the monitor to remain within the shelter while taking readings of the dose rate outside.

12.59 The most rapid method for obtaining radiation levels in a large area is by aerial survey. Because of their long range in air, gamma rays can be detected by sensitive instruments at a height of a few thousand feet. Low-flying airplanes or helicopters, carrying suitable radiation instruments for measuring dose rates, can survey large areas unimpeded by damage on the surface and by impassable streets and roads. Moreover, by making initial flights at an altitude of 1,600 feet or so, the dose rates are only about 1 percent of those on the ground, so that the hazard to the monitor is decreased accordingly.

12.60 The dose rates measured at an altitude must be multipled by an appropriate factor to give the approximate dose rates near the ground. This factor will depend primarily on the height above the ground and nature of the terrain. In the absence of more specific information, the data in Fig. 9.181 may be used to estimate the attenuation factor at a known altitude with reference to that at a height 3 feet above the ground.

12.61 The aerial survey is important because it can be made readily and can provide information which might be impossible to obtain in any other way at the time of interest. Nevertheless, such a survey can serve only as a rough guide and should be made only after all the early fallout is out of the air and on the ground. For points of special interest, the aerial survey must be supplemented by measurements made on the ground when it is safe to do so. The information obtained from the aerial survey will help, however, in planning the ground survey. In this way, the first appreciation of the broad aspects of the radiological situation will lead to the determination of conditions at critical points, to the establishment of dose-rate contours, and to the location of contaminated hot spots as well as the safest areas.

RADIATION DOSES AND TIMES IN CONTAMINATED AREAS

12.62 For the planning of defensive actions in connection with the residual activity from fallout or for carrying out survey operations in an area contaminated by the residues from a nuclear explosion, it is necessary either to make some estimate of the permissible time of stay for a prescribed gamma-radiation dose (in roentgens or rems) or to determine the dose which would be received in a certain period of time. The basic data are presented in the form of graphs in Chapter IX, but the same results may be expressed, in a somewhat more limited form, in tables that are more convenient for some purposes.

12.63 If the radiation dose rate (in roentgens or rems per hour) is known at a certain time at a given location, Table 12.63 may be used to determine the dose rate at any other time at the same location, *assuming that the fallout has descended completely and there has been no change other than that resulting from natural radioactive decay.* The same table can be utilized to determine the time after the explosion at which the dose rate will have attained a specific value. Suppose, for example, that at 5 hours after the explosion the measured dose rate is 6 roentgens per hour; when will it have decreased to 1 roentgen per hour? To obtain the answer, find the line in the left-hand column indicating "5 hours," and follow this horizontally until the value nearest to 6 is reached; this is 5.8, which is lower than the actual dose rate. Now proceed vertically down this column until the indicated value is somewhat less than 1.0; it is seen to be roughly 25 hours.

12.64 To determine the allowable time of stay in a contaminated area before a specified total dose is received, Table 12.64 may be employed if the dose rate at the time of entry is known. Suppose that upon entering a contaminated area at 8 hours after the explosion, the dose rate (R) is found to be 45 roentgens per hour. A competent authority has decided that exposed persons in the area may receive a total dose (D) of 25 roentgens, without endangering themselves, in order to perform an important mission; how long can they stay?

TABLE 12 63

FALLOUT ACTIVITIES AT VARIOUS TIMES AFTER A NUCLEAR EXPLOSION

Time after explosion	Dose rate																			
6 min	16	32	66	95	127	159	318	477	636	795	954	1 272	1 590							
12 min	7	14	28	41	55	69	138	207	276	345	414	552	691	1 380						
18 min	4 3	8 6	17	25	34	43	86	129	172	216	259	344	431	862	1 290					
30 min	2 3	4 5	9 1	13	18	23	45	68	91	114	136	182	227	456	681	908	1,140			
42 min	1 5	3 0	6 0	9 1	12	15	30	46	61	76	91	122	152	304	456	608	760	912	1 220	
1 hr	1 0	2 0	4 0	6 0	8 0	10	20	30	40	50	60	80	100	200	300	400	500	600	800	1 000
1 hr 30 min	0 6	1 2	2 4	3 7	4 9	6 1	12	18	24	31	37	48	61	122	183	244	305	366	488	610
2 hr	0 4	0 9	1 8	2 6	3 5	4 4	8 7	13	18	22	26	35	44	87	131	175	219	262	350	437
3 hr	0 3	0 5	1 1	1 6	2 1	2 7	5 4	8 0	11	13	16	21	27	54	80	107	134	161	214	268
5 hr		0 3	0 6	0 9	1 2	1 5	2 9	4 4	5 8	7 3	8 7	12	15	29	44	58	73	87	116	145
7 hr			0 4	0 6	0 8	1 0	1 9	2 9	3 9	4 9	5 8	8	10	19	29	39	49	58	78	97
10 hr				0 4	0 5	0 6	1 3	1 9	2 5	3 2	3 8	5 1	6 4	13	19	25	32	38	51	64
15 hr					0 3	0 4	0 8	1 2	1 6	1 9	2 3	3 2	3 9	7 8	12	16	19	23	31	39
1 day							0 5	0 7	0 9	1 2	1 3	1 8	2 3	4 5	6 8	9 0	12	13	18	23
1 d 12 hr							0 3	0 4	0 6	0 7	0 9	1 2	1 5	2 9	4 4	5 8	7 3	8 7	12	15
2 d									0 4	0 5	0 6	0 8	1 0	1 9	2 9	3 9	4 9	5 8	7 8	10
4 d												0 3	0 4	0 8	1 3	1 7	2 1	2 5	3 3	4 2
1 wk														0 5	0 7	0 9	1 2	1 4	1 8	2 3
2 wk																0 3	0 4	0 5	0 6	0 8
4 wk																			0 3	0 4

TABLE 12.64

ALLOWABLE STAY TIME IN AREA CONTAMINATED BY FALLOUT FROM A NUCLEAR EXPLOSION

	Time of entry in hours after the explosion																		
	0.1	0.2	0.5	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40
D/R	Duration of exposure (in hours and minutes) required to produce specified values of *D/R* for various times of entry after the explosion.																		
0.2	1-11	0-25	0-15	0-14	0-13	0-12	0-12	0-12	0-12	0-12	0-12	0-12	0-12	0-12	0-12	0-12	0-12	0-12	0-12
0.3	9-40	1-00	0-22	0-22	0-20	0-19	0-19	0-19	0-19	0-18	0-18	0-18	0-18	0-18	0-18	0-18	0-18	0-18	0-18
0.4	312-24	2-22	0-42	0-31	0-27	0-26	0-26	0-25	0-25	0-25	0-25	0-25	0-25	0-24	0-24	0-24	0-24	0-24	0-24
0.5	∞	6-12	1-02	0-42	0-35	0-34	0-32	0-32	0-32	0-31	0-31	0-31	0-31	0-31	0-31	0-30	0-30	0-30	0-30
0.6	------	19-20	1-26	0-54	0-44	0-41	0-39	0-39	0-38	0-38	0-38	0-37	0-37	0-37	0-37	0-37	0-37	0-36	0-36
0.7	------	82-06	2-05	1-08	0-52	0-49	0-47	0-46	0-45	0-45	0-44	0-44	0-44	0-44	0-43	0-43	0-43	0-43	0-42
0.8	------	624-48	2-56	1-23	1-02	0-57	0-54	0-53	0-52	0-51	0-51	0-51	0-50	0-50	0-49	0-49	0-49	0-49	0-49
0.9	------	2,000-00	4-09	1-42	1-12	1-05	1-02	1-00	0-59	0-58	0-58	0-57	0-57	0-57	0-56	0-55	0-55	0-55	0-55
1.0	------	∞	5-56	2-03	1-23	1-14	1-10	1-08	1-06	1-05	1-05	0-04	1-04	1-03	1-02	1-02	1-02	1-01	1-01
1.25	------	--------	15-30	3-13	1-54	1-38	1-31	1-28	1-25	1-24	1-23	1-22	1-21	1-20	1-19	1-18	1-17	1-17	1-16
1.5	------	--------	48-20	4-57	2-30	2-05	1-54	1-49	1-45	1-43	1-41	1-40	1-39	1-37	1-36	1-34	1-33	1-33	1-32
2.0	------	--------	1,562-00	11-52	4-06	3-13	2-46	2-35	2-29	2-24	2-20	2-18	2-16	2-13	2-10	2-08	2-06	2-05	2-04
2.5	------	--------	∞	31-00	6-26	4-28	3-48	3-28	3-16	3-08	3-03	2-59	2-55	2-51	2-46	2-45	2-40	2-38	2-36
3.0	------	--------	--------	96-39	9-54	6-09	5-01	4-28	4-10	3-58	3-49	3-43	3-38	3-30	3-24	3-17	3-14	3-11	3-08
4.0	------	--------	--------	3,124-00	23-43	11-05	8-12	6-57	6-16	5-50	5-33	5-19	5-10	4-58	4-44	4-32	4-26	4-20	4-15
6.0	------	--------	--------	∞	193-19	35-35	19-48	14-43	12-19	10-55	10-02	9-24	8-57	8-19	7-46	7-15	7-01	6-48	6-34
10.0	------	--------	--------	--------	∞	728-49	124-00	59-18	39-34	30-39	25-42	22-35	21-32	17-52	15-41	13-57	13-05	12-24	11-42

D/R=Allowable dose in roentgens divided by dose rate in roentgens per hour at time of entry.

The allowable dose (D) is divided by the dose rate (R) at the time of entry to give D/R, i.e., 25/45=0.55. This result falls between two values in the left-hand column of Table 12.64, and the smaller one is taken. Follow the D/R=0.5 line horizontally until the column headed "8 hours" after the detonation is reached. The allowable stay time is seen to be 31 minutes; for D/R=0.6, the corresponding time is 38 minutes, and so the actual permissible stay time would be about 34 minutes. By using both Tables 12.63 and 12.64, a variety of other estimates can be made.

12.65 There are two important reservations which must be kept in mind in using Tables 12.63 and 12.64. First, if there is any change in the situation, either by further contamination or by decontamination in the period between the two times concerned, the results will not be valid. Second, even if the conditions under which the tables are applicable are fulfilled, the estimates should be used for *planning purposes only*, and to provide a guide for any action that may be required. Changes in dose rates and total accumulated doses over a period of time must always be checked by instruments.

FOOD AND WATER

12.66 After a nuclear attack, in addition to protection from external residual radiation exposure, it is important that personnel in the fallout area also be protected from internal radiation exposure due to ingestion of radioactive fallout material along with food and water. Food and water are not adversely affected by exposure to the residual radioactivity. The principle of protection to be understood is that fallout material must be removed from food and water prior to consumption to prevent this material from getting inside the body. Relative to that which could be taken into the body by eating and drinking, it appears that the amount of radioactive material taken in by inhalation may be small (see §11.160). Nevertheless, air which contains fallout particles should not be directly inhaled without a protective respiratory device (such as a dust-filter respirator) until it is established by monitoring procedures that the air is free from radioactive contamination.

12.67 The contamination of emergency food and water supplies by residual radiation can be prevented by storing them in dust-tight containers. Although the outside of a container may become contaminated by fallout, most of the radioactive substance can be removed by washing the container before it is opened. The foods or fluids can then be removed and consumed without significant contamination.

12.68 If emergency food supplies do become contaminated, or if it is necessary to resort to contaminated sources after emergency supplies are exhausted, many types of food can be treated to remove the radioactive material. Fresh fruits and vegetables can be washed or peeled to remove the outer skin or leaves. Food products of the absorbent type cannot be decontaminated in this manner and should be disposed of by burial. Boiling or cooking of the food has no effect in removing the fallout material. Milk, from cows which survive in a heavily contaminated area, may not be safe to drink because of the radioiodine content and this condition may persist for weeks or months.

12.69 Domestic water supplies from underground sources will usually remain free from radioactive contamination. Water supplies from surface sources may become contaminated if watersheds and open reservoirs are in areas of heavy fallout. However, most of the radioactive fallout material would be removed by regular water treatment which includes coagulation, sedimentation, and filtration. If a surface water supply is not treated in this manner, but merely chlorinated, it may be unfit for consumption for several days after an attack. As a result of dilution and natural decay the contamination will decrease with time.

12.70 If the regular water supply is not usually subjected to any treatment other than chlorination, and an alternative source is not available, consideration should be given in advance planning to the provision of ion-exchange columns or beds for emergency decontamination use. Home water softeners might serve the same purpose on a small scale. The water contained in a residential hot-water heater would serve as an emergency supply, provided it can be removed without admitting contaminated water. Water may also be distilled to make it safe for drinking purposes. *It should be emphasized that mere boiling of water contaminated with fallout is of absolutely no value in removal of the radioactivity.*

DECONTAMINATION

12.71 Decontamination is the process of removing radioactive material from a location where it is a hazard to one in which it can do little or no harm. It is one of the means which are available for reducing the radiation dose that would be received from fallout. Preferably it should be accomplished under the supervision of personnel trained in decontamination procedures. Radiation measuring instruments should be used not only to determine the effectiveness of the decontamination but also to make sure that the contaminated material is disposed of in a safe manner.

12. 72 Because of its particulate nature, fallout will tend to collect on horizontal surfaces, e.g., roofs, streets, tops of vehicles, and the ground. In the preliminary decontamination, therefore, the main effort should be directed toward cleaning such surfaces. The simplest way of achieving this is by water washing, if an adequate supply of water is available. The addition of a commercial wetting agent (detergent) will make the washing more efficient. The radioactive material is thus tranferred to storm sewers where it is less of a hazard. Covering the ground around a building with uncontaminated earth or removing the top layer of the ground to a distance, by means of earth-moving equipment, are methods for reducing the dose rate inside a building. Inasmuch as decontamination of streets, buildings, and other large items requires substantial manpower and resources, the effectiveness of these operations will benefit from sound planning and skilled supervision.

12.73 It is important to note, in connection with removal of contaminated earth for the purpose described above or to provide a means of transit, that the gamma rays from fission products can travel considerable distances through air. For example, at 3 feet above the ground, roughly 50 percent of the dose rate received in the center of a large, flat, uniformly contaminated area comes from distances greater than 50 feet away, and about 25 percent from distances more than 200 feet away. Thus, complete removal of the contaminated surface from a circle 200 feet in radius would reduce the dose rate in the center to about one-fourth of its original value. However, if the contaminated earth were not completely removed, but just pushed to the outside of the circle, the dose rate would be considerably greater than one-fourth the initial value.

12.74 It is apparent, therefore, that if facilities are to be provided across open country which is contaminated over a large area, bulldozing the top few inches of contaminated soil to the sides will be satisfactory only if a wide strip is cleared. Thus, if the strip is 250 feet in width, the radiation dose rate in the middle will be reduced to one-tenth of the value before clearing. A similar result may be achieved by scraping off the top layer of soil and burying it under fresh soil. Something like a foot of earth cover would be required to decrease the dose rate by a factor of ten.

12.75 Badly contaminated clothing, as well as rugs, curtains, and upholstered furniture, would have to be discarded and buried or stored in an isolated location. When the radioactivity has decayed to a sufficient extent, or if the initial contamination is not too serious, laundering may be effective in reducing the activity of clothing and fabrics, to permit their recovery. Thorough vacuum cleaning of furniture might be adequate in some cases, but an instrument check would be necessary before further use.

SUMMARY

Planning Protection

12.76 In planning protection against the hazards associated with a nuclear attack, it must be recognized that the amount of protection that will be available to individuals is, in a large degree, directly related to the extent of public knowledge concerning nuclear weapons effects and associated protective measures, and to the steps taken prior to the attack to put these measures into a state of readiness. There are certain actions which can be taken by the unprepared in extreme emergencies, but the protection achieved is minor when compared to that which would be available to those who had made adequate preparations. Moreover, following an attack there are certain procedures that can tend to minimize the remaining hazards and these also will be made more effective by sufficient concern beforehand as to their implementation.

12.77 A massive, reinforced, fireproof shelter structure is required at close distances to protect individuals against the severe immediate effects (blast, thermal, and initial nuclear radiation) of a nuclear explosion. This type of protection is the most comprehensive and requires the greatest amount of preplanning effort and knowledge of the effects hazards. Conventional buildings may also be designed to be blast and fire resistant. Measures to minimize the thermal and fire hazard (§ 12.39 *et seq.*) may also be effected. In those areas where early fallout is expected to be a hazard, shelters may be constructed and provision made for occupying them for considerable lengths of time. Knowledge of warning systems and evacuation procedures will also minimize confusion. Moreover, possession of battery operated communications systems and of radiation monitoring equipment will make it possible to obtain information on the condition of the occupied area following an attack.

12.78 In the event that shelters are not available, certain evasive actions may prove helpful at distances where the immediate effects are least severe. By instantly falling prone and covering exposed portions of the body or getting behind opaque objects, much of the thermal radiation may be avoided, especially in the case of large-yield weapons. Under no circumstances should an individual look in the direction of the fireball. Staying behind thick walls or lying in a deep ditch may help to avoid initial nuclear radiation. All of the above actions will also help to decrease the possible danger from the blast wave. Moreover, persons should avoid areas which have frangible materials, such as window glass, plaster, etc., which may become flying debris by the action of the blast.

12.79 After the immediate effects of the nuclear explosion are over, certain acts are required to minimize the hazards of the early fallout and from the fires which may result from thermal radiation and secondary blast effects. First, if small fires can be quickly extinguished, extensive conflagrations may be prevented. This must be accomplished before the arrival of the fallout or in areas of low radioactivity levels. Some protection from the fallout may be secured in the basements of buildings or in a quickly constructed shelter, such as is described in §12.55. It is important to keep from coming into physical contact with the fallout particles, and to prevent contamination of food and water sources. Monitoring equipment should be used to determine areas which have safe radiation levels and decontamination efforts can proceed to recover necessary equipment, buildings, and areas.

CONCLUSION

12.80 Much of the discussion presented in earlier sections of this chapter have been based, for simplicity, on the effects of a single weapon. It must not be overlooked that in a nuclear attack some areas may be subjected to several bursts. The basic principles of protection would remain unchanged, but protective action against *all* the effects of a nuclear explosion—blast, thermal radiation, initial nuclear radiation, and fallout—would become even more important. There is a good possibility that many people would survive a nuclear attack and this possibility would be greatly enhanced by utilizing the principles of protection in preattack preparations and planning, in taking evasive action at the time of an attack, and in determining what should be done in the recovery phase after the attack.

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APPENDIX A

NUCLEAR WEAPONS SAFETY AND ACCIDENT HAZARDS

INTRODUCTION

A.1 Nuclear weapons are designed with great care to explode only when deliberately armed and fired. Nevertheless, there is always a possibility that, as a result of accidental circumstances, an explosion will take place inadvertently. Although all conceivable precautions are taken to prevent them, such accidents might occur in areas where the weapons are assembled and stored, during the course of loading and transportation on the ground, or when actually in the delivery vehicle, e.g., an airplane or a missile.

A.2 In general, nuclear weapons contain varying amounts of high explosive (§ 1.54), in addition to the fissionable material, i.e., the nuclear explosive. The chances that the latter alone will detonate are so remote that they can be ruled out completely. It is the high-explosive component which comprises the main possible hazard, just as it does with conventional weapons. The spontaneous detonation of this material, without external cause, is highly improbable, but an explosion might occur if the weapon were dropped from a height or if it were involved in a fire. Both aircraft and missiles contain fuel or propellant which is combustible and so in an accident to these vehicles a serious fire could develop which might possibly, although by no means certainly, cause the detonation of the high explosive in a nuclear weapon.

A.3 Even if such an explosion did occur, the nuclear component would not necessarily be affected. A nuclear weapon is a complex system and all of its components must function almost perfectly if it is to produce an energy release that even approaches the design value. Any nuclear energy contribution resulting from the accidental detonation of the high-explosive component will, therefore, be either completely absent or very small. During more than 16 years (from 1945 through 1961) of storing, transporting, flying, overhauling, modifying, inspecting, and otherwise working on and with nuclear weapons, the nuclear part of the weapon has not contributed to the cause or the effect of an accident. Although any accident is to be deplored, the fact that none has been more serious than from a conventional high-explosive weapon of moderate power, is a tribute to the extreme care devoted to the design of nuclear weapons and to the development of safe procedures for handling and transporting them.

A.4 Before discussing the various hazards which might be associated with an accident to a nuclear weapon, mention may be made of the possibility of a nuclear explosion being produced deliberately by sabotage or by the action of a psychotic individual who has access to a weapon. To eliminate or, at least, to minimize the probability of such an occurrence, there are positive physical and procedural measures which prevent deliberate or inadvertent arming, launching, firing, or release of a nuclear weapon. Among the precautions taken mention may be made of the use of launch or release controls which are locked or sealed in the safe position, the employment of two or more separate controls, and procedures requiring the presence of two or more properly informed and authorized persons.

A.5 Since accidents, by their very nature, are completely unpredictable, consideration must be given to all conceivable hazards that might arise in the storage or transportation of nuclear weapons. These hazards may be due to (*a*) fire and detonation of the high explosive, (*b*) fissionable material, i.e., uranium and plutonium, (*c*) tritium, which is radioactive, and (*d*) fission products in the unlikely event that there is an appreciable nuclear yield. These aspects of accidents to nuclear weapons will be considered in turn.

FIRE AND DETONATION

A.6 If a nuclear weapon is exposed to the flames from a gasoline or similar fire, arising from the fuel or propellant of the carrying vehicle, the high explosive will probably ignite and burn. Fires resulting from large quantities of burning high explosives are very difficult to extinguish. At the same time, acrid, suffocating, and toxic gases are produced, and a poisonous residue may remain. If the high explosive is confined, as in an intact weapon, detonation may occur at any time. In addition, high explosives melt at relatively low temperatures; the heat of the fire may thus cause the molten explosive to flow out of the weapon and then resolidify. In this state, the material is extremely sensitive to shock, and may detonate if stepped on.

A.7 In any accident involving a nuclear weapon, such as dropping or exposure to fire, there is a possibility that detonation of the high explosive may occur. However, one of the characteristics of TNT and similar explosives is the unpredictability of their response to a given stimulus. Thus, impact or a fire may or may not cause a detonation. If a detonation does occur, it can range from a very small to a large chemical explosion or it may be a series of small explosions. The breakage of a weapon due to impact or to a small explosion will probably result in scattering of small pieces of high explosive; these may burn and possibly explode.

A.8 Rough handling of high explosives as well as accidents can lead to the formation of powdered explosive. Under these conditions, most explosive materials are more unstable than in bulk form and are more apt to be detonated by shock or change in temperature. Exposure to sunlight also increases the sensitivity of high explosives; at the same time there is a change in color which makes small pieces and powder difficult to distinguish from their surroundings. The danger of an explosion is thereby increased.

A.9 The detonation of high explosives can cause injury to personnel by direct and indirect blast effects, as described in Chapter XI. The greatest danger is probably from flying debris, falling objects, fragments of glass, etc. It is recommended that, in the event of a nuclear weapon becoming involved in a fire, all persons not essential for damage control or recovery operation withdraw to a distance of at least 1,500 feet. This will minimize the injury potential of the blast that would result from the detonation of the high explosive.

A.10 Because of the formation of noxious fumes, etc., as stated above, produced by the burning explosive, and by any vehicle fuel that may be present, only those individuals properly protected with respiratory equipment should be permitted to remain in the downwind path of a fire or potential detonation. Smoke may be tolerated for a short period of time if necessary in the interest of saving lives. When the fire has subsided and a check has been made by instruments that no radiation hazard exists, trained experts may approach the scene of the accident in order to clear the area of scattered pieces of high explosive.

Fissionable Material

A.11 All nuclear weapons contain a certain amount of fissionable material, either uranium or plutonium (or both); these substances are radioactive, emitting alpha particles (§ 9.40). Following an accident to a nuclear weapon, the fissionable material could, in some circumstances, be spread over a large area. However, because alpha particles cannot penetrate even the dead surface layer of the unbroken skin, the only possible hazard that could arise would be the entry of uranium or plutonium into the body. The danger from plutonium lies in the tendency of this element to concentrate in the bone, where the continuous emission of alpha particles may cause significant injury. Uranium, on the other hand, acts mainly as a chemical poison, and fairly large amounts would have to be absorbed to produce any serious effect. Both uranium and plutonium can be detected as surface contamination by instruments which indicate the presence of alpha particles; the particles from plutonium have the higher energies.

A.12 Plutonium and uranium react readily with oxygen from the air and so they may become dispersed as small particles of oxide if the fissionable material is exposed. This may occur if the nuclear weapon is broken by impact or by the detonation of the high explosive. In the event of a fire, very fine particles of the oxides may be carried in the smoke. In the few instances in which aircraft containing nuclear weapons have burned, the fissionable material melted and was left on the ground as a slag. In this condition, oxides will form on the surface and may become airborne if disturbed, e.g., by the wind, to become an inhalation hazard.

A.13 As is the case with fallout particles (§ 11.156), significant entry of plutonium and uranium oxides into the body can occur through the respiratory tract; even then, the nose and lungs act as effective filters. Because of their small solubility, absorption of the oxides by the gastrointestinal system is very low. Furthermore, pentration of intact skin is impossible and although the material may enter where the skin is broken, it will be localized at the point of access. It may then be cleansed away, even at some later time, without appreciable translocation to the blood stream or other body tissues having occurred.

A.14 The results of observations made at the Nevada Test Site indicate that, at distances greater than 1,500 feet from the incident, the amounts of plutonium that might be received either from a contaminated smoke cloud or in other ways would not exceed the accepted Radioactivity Concentration Guide values (§ 11.100). For undisturbed surfaces, initial concentrations up to 100 micrograms of plutonium per square foot appear to be tolerable; for uranium the tolerance value is somewhat higher. The general conclusion drawn from the tests is that, even though the Radioactivity Concentration Guide for the body burden of plutonium is small (approximately half a microgram), it is difficult to acquire this amount as a result of a weapon accident outside the exclusion radius given above. The permissible concentration of uranium in the body is larger than for plutonium, and is not likely to be attained in the same circumstances.

TRITIUM

A.15 Tritium is another radioactive isotope used in weapons which could be hazardous in a confined area. In air tritium becomes an analogue of water, i.e., T_2O or HTO. In an enclosed space where the tritium water vapor can concentrate in the air, it can be easily absorbed through the unbroken skin, the lungs, and the gastrointestinal system, constituting an exposure problem to the entire body. Should it enter the body, tritium water dissolves in the body water and is eliminated at the same rate as ordinary water since it does not tend to concentrate in bone or in any organ as do some of the more hazardous radioactive materials.

A.16 From the point of view of the general public, the possibility of confrontation with a tritium hazard is negligible, for only selected military personnel can gain access to areas of enclosure which contain nuclear weapons. Because the existence of tritium in air can be detected by instruments sensitive to beta particles, monitoring systems are installed wherever necessary. The precautionary procedures employed to protect against the possible hazards from other radioactive materials in weapons provide more than adequate safeguards against tritium. The accepted Radioactivity Concentration Guide for this isotope is 3 millicuries distributed throughout the body. To accumulate such a dose it would be necessary to breathe for an hour air containing a concentration of 21 millicuries per cubic foot.

FISSION PRODUCTS

A.17 Fission products would be produced in an accident with a nuclear weapon only if there were a nuclear (fission) contribution to the energy released in a fire or explosion. The probability that there will be any nuclear yield at all is extremely small, but the possibility must, of course, be kept in mind. In no accident, to date, has there been any fission product release, although in some cases the weapon has become hot enough to cause the fissionable material to melt, as noted earlier.

A.18 If there should be any nuclear yield, the hazard would be mainly due to the beta particles and gamma rays emitted by the radioactive fission products. The effects would be similar to those arising from the residual nuclear radiation, as described in Chapter IX, but scaled down to the actual fission yield in the accident. In addition, neutrons released in the fission process may be captured by materials close to the explosion and so produce induced activity (§ 9.31), consisting of either beta particles alone or in conjunction with gamma rays. Both beta and gamma radiation are easily detected with the proper instruments, so that survey of an accident area will readily indicate if a fission energy release has occurred. If it has, then proper precautions must be taken in cleaning up the area. Incidentally, if the beta-gamma survey meter shows the presence of contamination, it may be taken for granted, without further test, that fissionable material (uranium or plutonium) is also present. As a general rule, it is expected that the radiation dose from fission products and induced activity delivered at a distance of 1,500 feet from the scene of the accident will be negligible.

PROTECTIVE MEASURES

A.19 The Department of Defense and the Atomic Energy Commission have several hundred teams of men, in various parts of the United States, who are trained to deal with accidents involving nuclear weapons. Since such an accident may occur anywhere, for example, as the result of the crash of an airplane carrying a weapon, it is imperative that fire, police, civil defense, public health authorities, and other emergency services should take appropriate action. If it appears at all practicable, the first step should be to rescue and assist injured personnel. Next, the nearest military installation or AEC office should be notified of the accident, so that a special team may be dispatched to the scene. At the same time advice may be obtained concerning further action. Meanwhile, the area surrounding the accident should be cleared of all non-essential personnel to a distance of at least 1,500 feet.

A.20 If there is a fire and it is apparent that the weapon is not burning or engulfed in flames, an attempt should be made to extinguish the fire with water, in the normal manner, from the upwind side only. If the water seems to accelerate the burning, then it must be stopped. The weapon should be kept cool by means of a water spray, since it is expected that the high explosive will not detonate if its temperature is maintained below 300° F. In cases where the weapon is not in the fire, the foam used for extinguishing fuel fires can be spread over the weapon to protect it from radiated heat from flames. The breaking down of a foam blanket on fuel with water streams must be avoided.

A.21 If the weapon is engulfed in flames or it is believed that the high explosive is burning, no attempt should be made to put out the fire. All personnel should then evacuate the area of 1,500 feet radius around the site of the accident because of the danger of detonation occurring. It may be mentioned that burning high explosive may sometimes be detected by jets of white flame coming out of the weapon ("torching"), but this is not always observed. Consequently, if the flames, such as those produced by burning fuel, appear to be growing in intensity and extending toward or actually enveloping the weapon, all personnel should be removed from the scene.

A.22 The area downwind from the accident should be kept clear in order to avoid the toxic, and possibly radioactive, smoke from a burning weapon. If exposure to dense smoke is necessary for any length of time, dust-filtering masks and goggles, or special breathing apparatus, should be used. But the lack of such equipment should not hold up rescue efforts which require a short stay in the smoke area. Personnel who have been exposed to smoke must be monitored for radioactivity and, if necessary, decontaminated by members of the special team trained for the work. In fact, such action is advisable for all personnel who may have been contaminated in any way. They should be prevented from wandering about, since this would spread the radioactivity and make it more difficult to clear up.

A.23 If the special team has not arrived by the time the fire has subsided or been extinguished, no attempt should be made to clean up the scene of the accident. It may be highly radioactive and could represent a serious radiation hazard. For the same reason, the area of the accident should be roped off so as to prevent access by anyone, other than members of the survey teams. After they have made a careful examination of the area, they will either undertake its decontamination or will advise on what should be done in the interests of safety and security.